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PILOT PERFORMANCE, TRANSFER OF TRAINING AND DEGREE OF SIMULATION:

III. PERFORMANCE OF NON-JET EXPERIENCED PILOTS VERSUS SIMULATION FIDELITY

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ABSTRACT

This is the fourth report in a study program dealing with pilot performance, transfer of training and degree of simulation. The purpose of this study was to repeat a previously conducted transfer of training study using non-jet experienced pilots as subjects. Its primary objective was to determine the training feasibility of using degraded levels of simulation fidelity in an Operational Flight Trainer (OFT). Simulation fidelity was varied by incorporating coefficient changes into the aerodynamic equations of flight such that rigid coefficients and least squares approximations to flexible coefficients served as the experimental conditions and flexible coefficients served as the control condition. On the basis of study results, it was concluded that the feasibility of rigid coefficients for OFT training had been demonstrated; however, the training utility of the least squares approximations was doubtful. It is recommended that further study should be undertaken using other flight regimes and training maneuvers.

FOREWORD

This study was initiated by the Human Factors Laboratory, Naval Training Device Center, Orlando, Florida. It represents a portion of the program conducted under Task 7619, Degree of Simulation vs. Pilot Performance, the purpose of which was to examine pilot performance over a range of conditions of fidelity of aerodynamic simulation. Data collection took place at the UDOFFT facility Garden City, New York during the period November 1966 through April 1967.

This report is the fourth of six reports of research conducted by Life Sciences, Inc., Dr. W. G. Matheny, principal investigator. The six reports in the Task 7619 series are:

1. Demaree, R.G., Norman, D.A., and Matheny, W.G. AN EXPERIMENTAL PROGRAM FOR RELATING TRANSFER OF TRAINING TO PILOT PERFORMANCE AND DEGREE OF SIMULATION. NAVTRADEVCEN 1388-1, Naval Training Device Center, Port Washington, New York 1965.

2. Wilkerson, L.E., Norman, D.A., Matheny, W.G., Demaree, R.G., and Lowes, A.L. PILOT PERFORMANCE, TRANSFER OF TRAINING AND DEGREE OF SIMULATION: I. VARIATIONS IN PROGRAM CYCLE TIME AND AERODYNAMIC EQUATIONS. NAVTRADEVCEN 1388-2, Naval Training Device Center, Port Washington, New York, 1965.

3. Ellis, N.C., Lowes, A.L., Matheny, W.G., Norman, D.A. and Wilkerson, L.E. PILOT PERFORMANCE, TRANSFER OF TRAINING AND DEGREE OF SIMULATION II. VARIATIONS IN AERODYNAMIC COEFFICIENTS. NAVTRADEVCEN 1889-1, Naval Training Device Center, Orlando, Florida, 1967.

4. This report

5. Lowes, A.L., Ellis, N.C., Norman, D.A., Matheny, W.G. IMPROVING PILOTING SKILLS IN TURBULENT AIR USING A SELF-ADAPTIVE TECHNIQUE FOR A DIGITAL OPERATIONAL FLIGHT TRAINER. NAVTRADEVCEN 0034-2, Naval Training Device Center, Orlando, Florida, 1968.

6. Matheny, W.G., and Norman, D.A. THE EFFECTIVE TIME CONSTANT IN TRACKING BEHAVIOR. NAVTRADEVCEN 0034-3, Naval Training Device Center, Orlando, Florida, 1968.

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1.0 INTRODUCTION

This report documents results of the fourth study in a series of programmed investigations dealing with pilot training research where primary emphasis is given to pilot performance, transfer of training and conditions of simulation. These studies were conducted by Life Sciences, Inc. (LSI) under contract with the Naval Training Device Center (NTDC). Background and objectives for the present study are given in paragraphs to follow.

1.1 BACKGROUND

The task of defining simulator requirements for pilot training facilities has been of specific interest to the Military for several years. As a result of this interest, a great amount of data has been generated (See Muckler, et al., 1959; and Smode and Hall, 1966). Despite these many efforts, one of the persisting problems to defining simulation requirements is fidelity of simulation. According to the Smode and Hall survey, definitive answers to this particular problem have not yet been found.

Lacking definitive data the prevailing practice in the design and development of Operational Flight Trainer (OFT) simulators is to provide "high engineering fidelity" between the simulator and the aircraft. Although this practice in the past has not always been optimal with respect to cost, more recent studies de-emphasize this particular factor. The point apparently is that recent advances in the equipment state-of-the-art have significantly reduced the underlying costs associated with engineering fidelity, but firm conclusions on this aspect should wait for more complete data.

Aside from cost, one important trend in recent research is a growing challenge to a belief which underlies the prevailing practice in simulator development. This belief pertains to the idea that the higher the simulator fidelity (i.e., the closer it resembles the aircraft), the better the training. Although this line of thinking sounds quite plausible, its validity has certainly been questioned recently. As a matter of fact, Smode and Hall (1966) report that, "There is considerable evidence, ... that deliberate deviations from fidelity of simulation may lead to higher levels of transfer than does exact simulation." The potentiality of this outcome points up the fact that there is a real gap in knowledge regarding correlations between OFT system characteristics and training effectiveness. One of the aims of the present program is to provide information for reducing this gap. From the beginning LSI's purpose has been the conduct of studies to define and quantify OFT system characteristics which are cost effective but more importantly serve as predictors of transfer of training.

The general approach adopted by LSI in the overall program supported by NTDC is: (1) to define quantifiable parameters or characteristics of the OFT computer/simulator complex considered meaningful to the learning process; and (2) to conduct transfer of training studies using variations in these parameters as experimental conditions in simulated flight maneuvers employing the Universal Digital Operational Flight Trainer Tool (UDOFTT). Two variables were selected for study during early program planning: program cycle time and the aerodynamic equations of flight.

In the initial transfer of training feasibility studies as reported in NAVTRADEVCEN 1388-2 (Wilkerson, et.al., 1965), the effects of two program cycle times, 50 and 80 miliseconds, and two sets of aerodynamic equations, a complete and incomplete set, were investigated. The longer program cycle time and the incomplete set of equations represented deviations from high fidelity simulation. Since no differential effects in piloting performance were present at transfer after training on these lower fidelity simulations when compared with transfer performance after training on a high fidelity simulation, it was concluded that these are the types of OFT computer/simulator parameters which require closer study.

Since detailed studies of both parameters could not be accomplished simultaneously, a decision was made to select one parameter best suited to the objectives of the program. In this case, the aerodynamic equations were selected. In subsequent studies reported in NAVTRADEVCEN 1889-1 (Ellis, et.al., 1967), simulation fidelity was degraded by using: (1) rigid airframe aerodynamic coefficients in the aerodynamic equations, and (2) a least squares straight line fit to the aeroelastic aerodynamic coefficients. To investigate the training effectiveness of these conditions of simulation, three transfer of training studies were conducted in which flexible airframe aerodynamic coefficients (high fidelity simulation) were used to simulate the transfer task. The first study was conducted within the longitudinal mode of flight; the second, within the lateral mode; and the third, within the combined longitudinal and lateral modes. At the root of these studies was the hypothesis that one or both of these restricted conditions of simulation would form an effective basis of training for subsequent transfer to high fidelity conditions of simulation. As a consequence of the study, it was concluded within the limits of the investigations that these restricted levels of simulation were feasible conditions for training.

The foregoing discussion provides the necessary background for introducing the present study. Therefore, attention will be given in the remaining paragraphs of this section: (1) to identifying the problem and associated hypothesis of the study: and (2) to defining the study objective.

1.2 PROBLEM AND HYPOTHESIS

A general hypothesis advanced by LSI in previous contractual work with NTDC is that training or practice on restricted conditions of simulation defined within the aerodynamic equations of flight can serve as an effective basis for transfer to high fidelity conditions of simulated flight (NAVTRADEVCEN 1388-1: Demaree, Norman and Matheny, 1965). Given that the hypothesis is tenable, significant implications are that specifically defined levels of low fidelity simulation can be used during training without loss in training quality, and that the gap in knowledge which exists regarding OFT system characteristics and training effectiveness will be reduced.

Several alternatives for reducing simulation fidelity have been investigated by LSI as previously discussed in para. 1.1, and data resulting from these studies support the general hypothesis. It is significant to note, however, that these studies were conducted using highly experienced jet pilots as subjects. Although it was necessary for several technical reasons to employ experienced pilots in these initial feasibility studies, an important question is: To what extent did their performance under study conditions depend upon past experience? Since this question could not be completely resolved in these earlier studies, the validity of the general hypothesis with respect to lesser experienced pilots remained an unsettled issue, and yet it is to lesser skilled pilots that training data of this sort should have application if it is to be useful. The present study is aimed at resolving this question, and it is postulated for study purposes that the general hypothesis is valid with low experienced non jet pilots.

1.3 OBJECTIVE

The general objective of the study program of which the present investigation is an integral part is to establish relationships between conditions of simulations for given dimensions of piloting tasks and amounts of training. Of principal importance in the investigation detailed herein is the task of verifying with lesser experienced pilots the validity of relationships between particular conditions of simulation fidelity and training effectiveness as were demonstrated in NAVTRADEVCEN 1889-1 (Ellis, et. al., 1967)

In this case, simulation fidelity is defined in terms of the aerodynamic equations of flight where high fidelity is represented by flexible aerodynamic coefficients in the equations and low fidelity is represented by rigid coefficients and by a least squares fit to the aeroelastic equations. Non jet-experienced pilots are to receive practice in the UDOFTT on low fidelity simulation and then transferred to conditions of high fidelity simulation for subsequent comparisons with a similar group of pilots who are to receive practice on high fidelity simulation.

2.0 APPROACH AND RATIONALE

LSI's general hypothesis, the reader will recall, is that practice on restricted conditions of simulation fidelity defined within the aerodynamic equations of flight can serve as an effective basis for transfer to high fidelity conditions of simulated flight. The implication is that "high engineering fidelity" is not required in the design and development of Operational Flight Trainers. Previous studies by LSI demonstrated the feasibility of this hypothesis with highly experienced jet pilots. The primary objective of the present study is to establish the validity of the hypothesis with pilot samples corresponding more to the types of pilots found in primary training. Before describing the approach and underlying rationale employed to accomplish this objective, the major limitations imposed on the study and beyond control of the investigators will be identified.

2.1 STUDY LIMITATIONS

Although it is the purpose of every experimenter to conduct the type of investigation which unquestionably accomplishes his study objective, this is rarely the case. Practical limitations are always present. In the present study, the limitations of primary concern all related to the OFT simulation facility. The UDOFTT is a fixed base simulator, and it does not have a visual attachment; therefore, the study was necessarily conducted without either motion or real world visual cues. The former limitation certainly raises the question of whether or not the study data can be generalized to the operational training situation employing real aircraft, but data generalization, of course, is always a problem in controlled research. The latter limitation probably poses the most difficult problem of the two with respect to the specific study objective. Not having a visual attachment requires that all maneuvers be accomplished under IFR conditions, and in this case the pilot-participants must necessarily be instrumented-rated pilots. As a result, the original desire to use pilots who closely resemble the types of pilots found in primary training is somewhat compromised. Pilots in primary training are not usually instrument-rated.

Despite these limitations, the investigators felt that the results of the present study would provide useful information with respect to establishing the correlation between fidelity of simulation and transfer of training.

2.2 SELECTION OF PILOT SAMPLE

In selecting pilot-participants who corresponded as closely as possible to the types of pilots found in primary training, three criteria were used. These are ranked as follows:

(1) Instrument-rated pilots having reciprocating engine experience only were selected initially.

(2) From this group, pilots having the lowest number of flight hours were selected (Average flight time of pilots comprising the final sample equaled 500 plus or minus 50 hours).

(3) Finally, of this group private pilots had first priority in the test sample, and flight engineers from the commercial airlines were used as necessary to complete the sample.

Although these criteria do to some extent compromise the original intention of having pilot·participants who resemble pilots in primary training, they nevertheless represent reasonable concessions when considering the limitations discussed in paragraph 2.1.

2.3 STUDY PLAN

The study itself was planned and conducted to determine the training effectiveness of two conditions of degraded simulation fidelity. Both conditions were specifically defined in terms of the aerodynamic equations of flight. In one case, fidelity was degraded by using rigid coefficients in the equations, and in the other fidelity was degraded by using a straight line fit to the aeroelastic coefficients (See pages 8 - 11 for additional details).

The study plan entailed using lesser experienced pilots in the replication of Experiment Three described in NAVTRADEVCEN 1889-1 (Ellis, et. al., 1967). Briefly, this is a transfer of training study, and the procedure is to provide pilot groups (Experimental Groups) with defined amounts of practice in the UDOFTT on the degraded levels of simulation fidelity, and then transfer them to a condition of high simulation fidelity. Performance comparisons are then made between these pilots at transfer and a Control Group of pilots who has received practice on the transfer task.

Results of these comparisons will support one of the following three alternatives:

(1) The pilots in the Control Group will be significantly more efficient (smaller flight error or smaller deviation from prescribed flight path) in performing the transfer task.

(2) The pilots in the Experimental Groups will be significantly more efficient on the transfer task.

(3) Essentially, no significant differences in performances will exist between the two groups.

Data supporting alternative (1) would, of course, reject the training effectiveness of these particular levels of simulation fidelity. However, if alternative (2) were the case, the implication is that high engineering fidelity in the OFT simulator/computer complex is not necessary, but more importantly it is not desirable. The question of necessity would be resolved similarly if resulting data supported alternative (3), but the question of desirability would remain unanswered.

Alternative (3) served as the hypothesis in the present study. Using the null hypothesis in human engineering research is discussed by Ellis, (1967). Details regarding the rationale underlying other aspects of the study such as flight maneuvers, performance parameters and scoring methodology are discussed in NAVTRADEVCEN 1889-1 (Ellis, et.al., 1967) and will not be repeated here.

3.0 METHOD

The present program incorporated the designs, techniques and procedures developed under LSI's previous work with NTDC (See NAVTRADEVCEN 1889-1: Ellis, et. al., 1967). Therefore, the methodology essentially entailed replicating a previously conducted transfer of training study. General program items are discussed in the following paragraphs.

3.1 SUBJECTS

Eighteen (18) instrumented-rated pilots without jet experience served as subjects. Some of the subjects were recently hired flight engineers with the commercial airlines, but the majority were private pilots. The average flight time per pilot for the sample was approximately 500 hours. To facilitate learning cockpit layout and use of the instruments in the UDOFTT, each pilot received a program of instruction via an Audio Visual Training Device developed by LSI under previous contract with NTDC (See Appendix A, Page 47 for additional information).

3.2 CONDITIONS OF SIMULATION

Equipment - As mentioned previously, the OFT employed was the Universal Digital Operational Flight Trainer Tool (UDOFTT). The UDOFTT is a high-speed stored-program digital computer with two simulator cockpits and an instructor station. An on-line graphic recorder (CEC) and an off-line typewriter output was also used. A complete description of the UDOFTT facility is given by Sylvania (1963).

The aircraft simulated was a current high performance, swept wing, single engine jet fighter. A clean in-flight configuration was employed, and a modified engine capable of providing 1.55 Mach at 35,000 ft. without afterburner was used. The simulated flights were conducted in clear air (without turbulence).

Simulation Equations - The aeroelastic equations to be used as bases for deriving the experimental conditions of the present investigation are detailed in NAVTRADEVCEN 1388-2 (Wilkerson, et. al., 1965). The simulation equations for the rate-of-turn indicator were modified so that the turn needle displayed rate of change of heading rather than rate at which the aircraft turned about its body axis, as is normally the case. This was necessitated because some confusion on the part of pre-test subjects during earlier studies indicated that pilots are typically not aware that turn needle deflection decreases with increased bank angle, for a constant rate of heading change. The change insured indications independent of bank angle and reduced variability in turning performance due to misinterpretation of the instrument indication.

An additional change was already present in the Needle-Ball Indicator program such that the ball under certain conditions of flight indicates expected information rather than correct information about the side slip angle. By way of explanation, this change was necessitated in an earlier LSI study in which pilot-participants were required to fly a manever subjecting them to less than 1 g flight. In the present study, the pilot-participants were flying a maneuver at levels above 1 g. The program change was permitted to remain; however, since the method used to make the program adjustments does not in anyway affect ball response in greater than 1 g flight.

The integration formula used to solve the simulation equations was 0_{33} Mod Gurk, and a solution rate of 20 solutions per second corresponding to a program cycle time of 50 msec. was employed.

Experimental Conditions - Three conditions of simulation were employed: (1) Flexible airframe data, (2) Rigid airframe data, and (3) least squares approximations. Condition one served as a control for conditions two and three. Illustrative examples of each condition is presented in Figure 1, Page 9 for the stability derivative, C_{m_q} (pitch damping).

In Figure 1, functional dependencies for the stability derivatives are identified for each experimental condition. Under flexible conditions, derivatives depend on variations in both Mach and altitude, and under both rigid and least squares conditions they depend only on Mach.

To understand the derivation of the least squares approximations, two rather simple concepts of flight aerodynamics must be recalled. In the first place, all aircraft, to operate safely, must be flown within certain speed-altitude restrictions imposed by system design. Secondly, each aircraft has its own peculiar set of restrictions, and these make up what is called the flight envelope of that aircraft. In the present study program, the flight envelope was the primary basis for deriving the least squares approximations to the flexible aerodynamic coefficients.

Figure 2, Page 10, is a graphical representation of the flight envelope of the jet aircraft simulated in the present investigation. Included within the envelope shown in this figure are three different zones of flight operation, each varying with respect to amount of restrictions imposed on the aircraft. For study purposes, it was assumed that amount of flying in each zone would be inversely related to imposed restrictions, i.e., the aircraft under normal conditions would frequently be flown in lesser restricted areas. In line with this assumption, it was then felt that simulation of this aircraft should primarily be considered from the standpoint of increased flight accuracy in the more frequently used zones of operation. Therefore, a least squares approximations of the coefficients, as they vary with Mach, was obtained by a weighting technique in which coefficient values were weighted at 10,000 ft. altitude

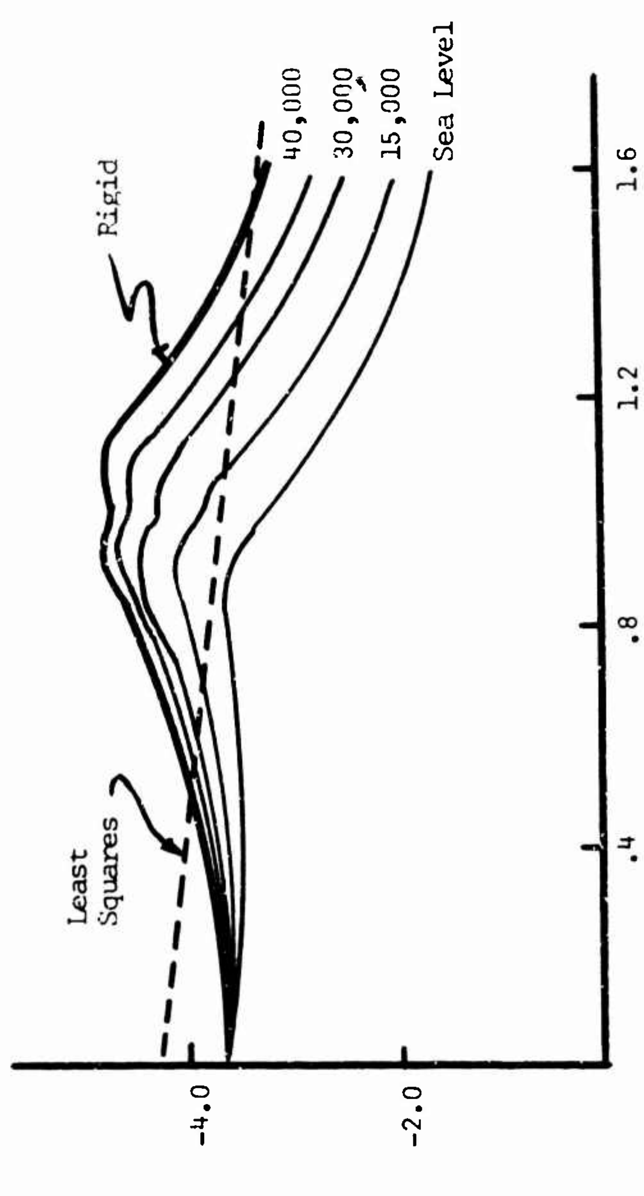

Figure 1. Sample Aerodynamic Coefficient Showing Mach and Altitude Variations for a Flexible Aircraft, a Rigid Aircraft and a Least Squares Approximation of the Flexible Aircraft

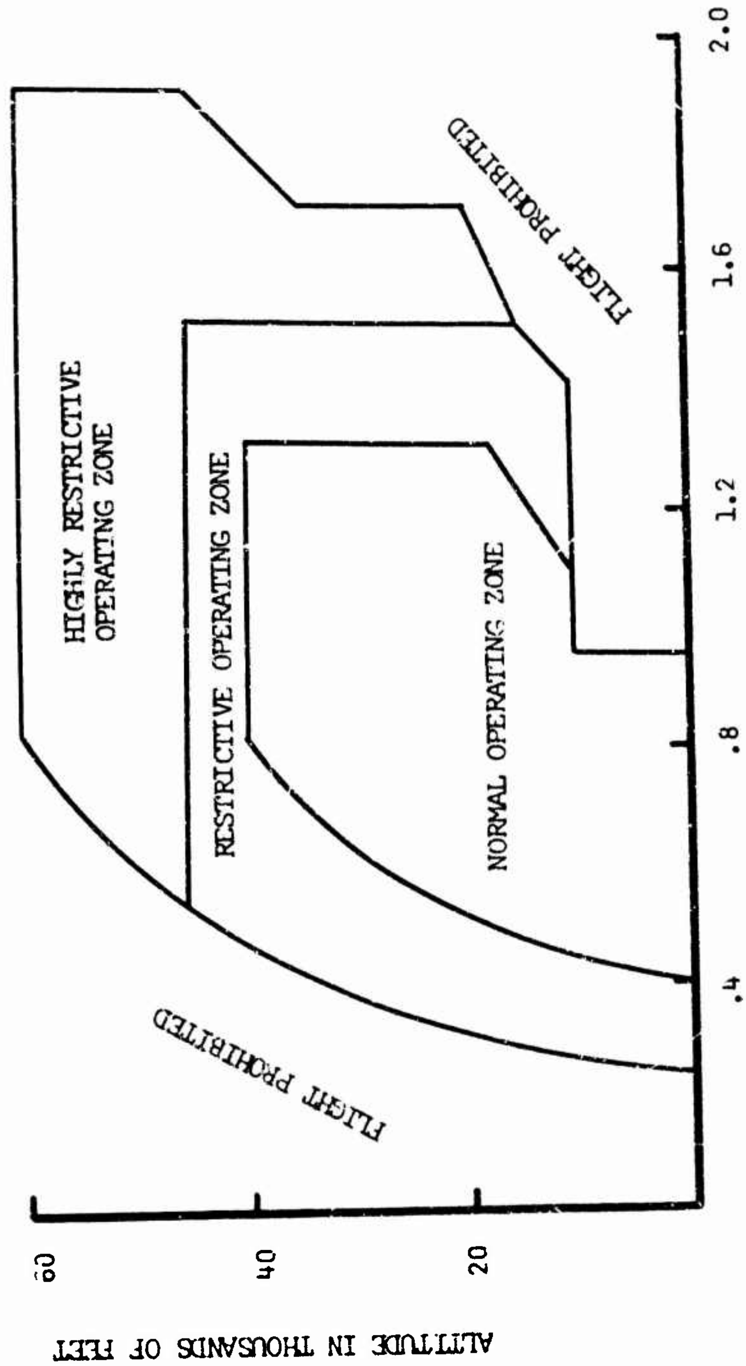

Figure 2. Flight Envelope of Jet Aircraft Simulated in Study

increments and 0.2 Mach number increments with numbers of 0, 1, 2, or 3. The magnitude of a weight given to a stability derivative was dependent upon the zone containing that derivative; i.e., weighting was largest for the more frequently used zone (least restrictive zone).

For example, in Figure 2, Page 10, a stability derivative for Mach 0.8 at 20,000 ft. would be given a weight of 3; at 42,000 ft., it would be given a weight of 2; at 50,000 ft., a weight of 1. Weighting was then accomplished in the least squares conditions simply by using each point three times if it had received a weight of 3, two times if it had received a weight of 2 and so forth.

Open-Loop Pulse Tests - Open-loop pulse tests were conducted prior to the start of subject testing. These tests consisted of pulsing the system through either the aileron, the elevator or the rudder controls, or simultaneously through the aileron and elevator controls. The results of these tests provided some estimate of day to day reliability of system operation and assisted in interpretation of the data.

Experimental Controls - Several controls were used during this investigation to assure that conditions of the experimental design were inserted into the computer program. These are as follows: (1) all conditions were changed in the program through a discrete button on the computer console rather than by inserting program changes through program change cards; (2) an identifying code for each condition was typed out by an off-line electric typewriter during initial condition print-out; (3) three parameters of the initial condition print-out were checked against hand computed values calculated from the results of the open-loop pulse tests prior to initiating a run; [these parameters, elevator surface position (δ_{is}), angle of attack (α), and pitch angle (θ) were maintained within five percent of the computed values or the program was rechecked]; and (4) at the completion of each run, print-out of data and CEC records were subjectively checked for "reasonableness." All of these study controls were designed to identify program errors at the earliest possible opportunity.

Maneuver - The maneuver designed to test pilot performance in the present study was a 360 degree standard rate turn with a 2000 fpm climb during the first half of the maneuver and a constant altitude turn during the second half (See Figure 3, Page 12). Subjects started with 30 seconds of straight and level flight (SLF) at 24,000 ft. before commencing a standard rate (3°/second) 2000 fpm climbing turn to the right. After one minute, and a change of heading of 180° and 2000 feet of altitude, subjects continued the standard rate turn maintaining their new altitude of 26,000 ft for another minute and a further 180° change in heading. At the end of two minutes, following a total change of 360 degrees of heading and 2000 feet of altitude, subjects rolled out on the original heading of 0° and continued for an additional 30 seconds. During the entire maneuver the subjects were instructed to maintain Mach 1.1.

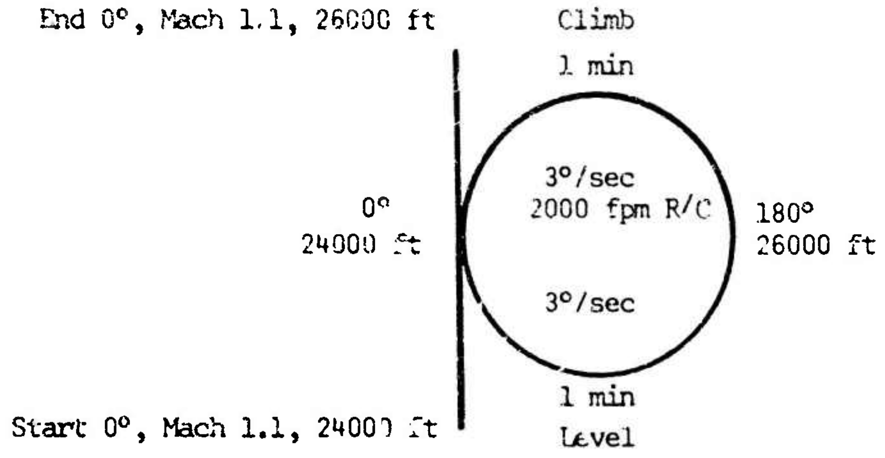

Figure 3. Diagram of Test Maneuver

3.3 EXPERIMENTAL DESIGN

Experimental Paradigm - The experimental design and transfer of training paradigm is presented in Table 1. Each group received 22 trials. Trials 1-10 served as training trials, 11-12 as transfer trials, and the final 10 trials provided a basis for evaluating long term effects of training.

Table 1

Experimental Design

Groups		Conditions	
A	Control	1	Flexible data
B	Experimental	2	Rigid data
C	Experimental	3	Least squares data

Transfer Paradigm

Groups	Pre-Training Condition	Trials	Transfer Condition	Trials	Post-Training Condition	Trials
A	1	10	1	2	1	10
B	2	10	1	2	1	10
C	3	10	1	2	1	10

Scoring - Objective measurements of both the pilots' control inputs and the outputs of the simulated system were obtained during test maneuvers. These included: (1) average absolute deviations (error) from programmed flight path, computed for altitude, Mach number and heading; (2) average algebraic deviations; computed for altitude, Mach number, and heading; and (3) mean and variance of aileron and elevator surface motions, fore/aft stick, elevator trim, lateral stick and aileron trim. Data samples for absolute and algebraic deviations of altitude, heading and Mach were taken each second while the data samples for the control surface motions were taken every one-half second. In order to measure pilot performance two scoring intervals were programmed into the computer, one during the climbing turn portion of the maneuver and the other during level portion. The first scoring interval began ten seconds after initiation of climbing turn or forty seconds after start of maneuver. The second scoring interval began ten seconds after initiation of level turn or 100 seconds after start of maneuver. Integrated performance data were stored by the computer and a CEC recorder provided continuous records of the data channels.

In addition to objective measurements, subjective evaluation of the simulated system was obtained from the participants through use of a pilot rating scale developed by Life Sciences, Inc. (See Appendix B, Page 51).

Data Analysis - Graphs were produced by plotting performance data across trials including training, transfer and post-training trials. These graphs provide a quick and easy assessment: (1) of performance change with practice on the various levels of simulation fidelity (i.e., learning); (2) of the practice effects at transfer: and (3) of the long term practice effects (as defined in the study design) during post-training. In addition, these graphs also provide insight into the types of changes in the aircraft/simulator system resulting from varying the aerodynamic coefficients. A statistical assessment of the practice effects of the various conditions of simulation fidelity at transfer and during post-training was made using non-parametric Ratio Tests (Dixon and Massey, 1957) of the performance data. Finally, non-parametric Sign Tests were used to compare performances of the experimental groups with the control group performance across trials for both training and post-training. These analyses provide evaluations of variations in both control inputs and system outputs as a function of the experimental conditions.

3.4 PROCEDURE

In order to obtain three matched groups of pilots, a larger parent group was tested on an audio-visual programmed maneuver and a UDOFTT test maneuver using flexible data in the simulation equations (See Appendix A, Page 47 for additional information of audio-visual program).

Subjects were then matched on the basis of their performance and assigned to three groups. After additional audio-visual instruction, groups were assigned to three conditions of simulator training such that one group was trained under equations using flexible aerodynamic coefficients; a second group, under equations using rigid aerodynamic coefficients; and the last group, under least squares approximations of the aerodynamic coefficients. Subjects who were trained with the set of equations incorporating flexible aircraft data served as a control group for the other two groups.

On arrival at the UDOFTT facility, pilots were briefed on instrument and control functions, maneuver timing, approximate pitch angles and so forth. In addition, pilots were given written sets of instructions regarding the maneuver to be flown (See Appendix C, Page 57). With the simulator in a "freeze" status, subjects during the first experimental session received five minutes of cockpit familiarization in which they manipulated controls and observed corresponding activity of instruments. Pilots then left the cockpit, and the simulator was prepared for experimentation.

On return to cockpit, pilots were provided a sketch of prescribed maneuver which they kept on their knee pad. At the beginning of each trial, the experimenter trimmed the simulator and centered the control.

The simulator was released to subjects as the second hand on the clock in the simulator cockpit passed through the six o'clock position. This allowed the subjects to begin the critical timing of both climb and descent on the 12 o'clock position of the sweep second hand.

Following fifth and tenth trials of training, and second trial of transfer, and fifth and tenth trials of post-training, each subject completed a pilot rating scale (Appendix B, Page 51). In addition, subjects were given the opportunity to make verbal evaluations which were recorded on tape for subsequent study.

4.0 RESULTS AND DISCUSSION

Data results are summarized and statistically evaluated in the following figures and tables. Figures 4-17, Pages 16 and 29, depict variations in pilot performances across trials for each of the three groups of pilots. The data in these figures provide a visual assessment: (1) of pilot performances by groups during practice on the defined conditions of simulation fidelity, and (2) of the effects of this practice upon both the transfer task as well as subsequent post-training trials.

Table 2, page 30, summarizes results of statistical tests made in comparing experimental and control group performances during both training and post-training. The first column of this table defines the particular groups being compared, and the second column identifies the parameter used for making the comparison. Entries in the remaining columns are the results of statistical evaluations, and they represent the probability of whether or not differences in group performances which occurred during the experimental trials were consistently different. At this point, directional differences are of primary concern rather than differences in magnitude; therefore Sign Test comparisons were made. Probabilities equal to or less than .05 were interpreted as indicating that performances are different.

Tables 3 and 4, pages 31 and 32, summarize results of comparative tests examining performances of the Experimental and Control Groups on transfer trials. Column (1) of this table identifies the two phases of the simulated maneuver, and Column (2) contains a listing of the parameters which were used to score pilot performance. Average performances of the pilot groups are entered in the next two columns, Control Group in Column (3) and Experimental Group in Column (4). The ratios (E/C) of these scores and a corresponding statistical evaluation of each ratio are given in Columns (5) and (6) respectively. Probabilities equal to or less than .05 were interpreted as indicating that performances are different. These tables provide a statistical evaluation of each individual performance parameter thereby providing what might be called a microassessment of the training value of each of the conditions of simulation fidelity.

Tables 5 and 6, pages 33 and 34 are identical to the two previous tables with the exception that in these tables comparisons are made between the Experimental and Control groups on the last four post-training trials. Within the constraints of the experimental design, these comparisons provide an assessment of the long-term effects of practice on the conditions of simulation fidelity.

Since the present study is a replication of a previous investigation, an appropriate framework around which the data results can be structured for discussion already exists. Briefly, the principles of this framework are contained within the following statements:

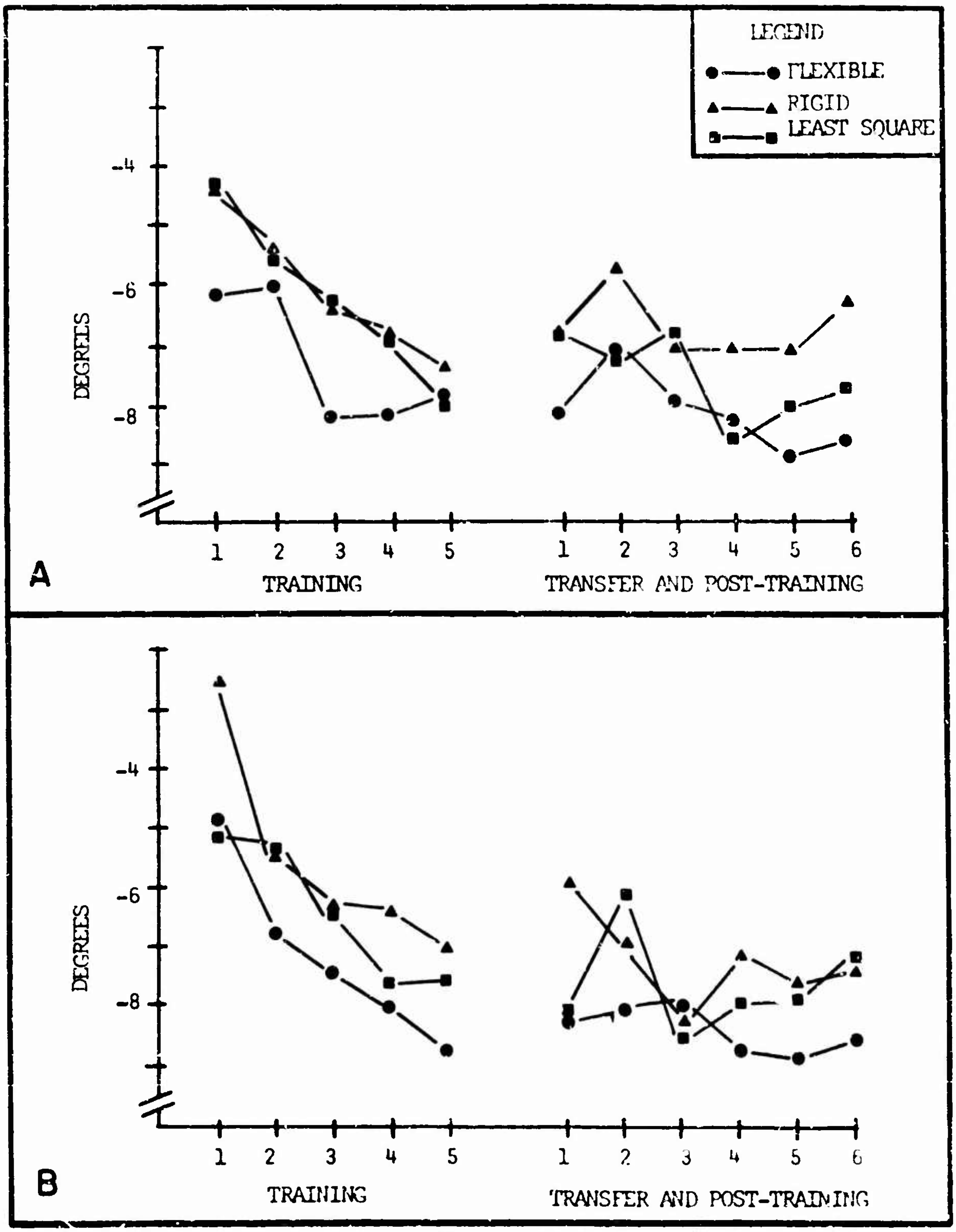

Figure 4. Average Performances of Experimental and Control Groups in Climbing Turn (A) and Level Turn (B) as Measured by Fore/Aft Stick.

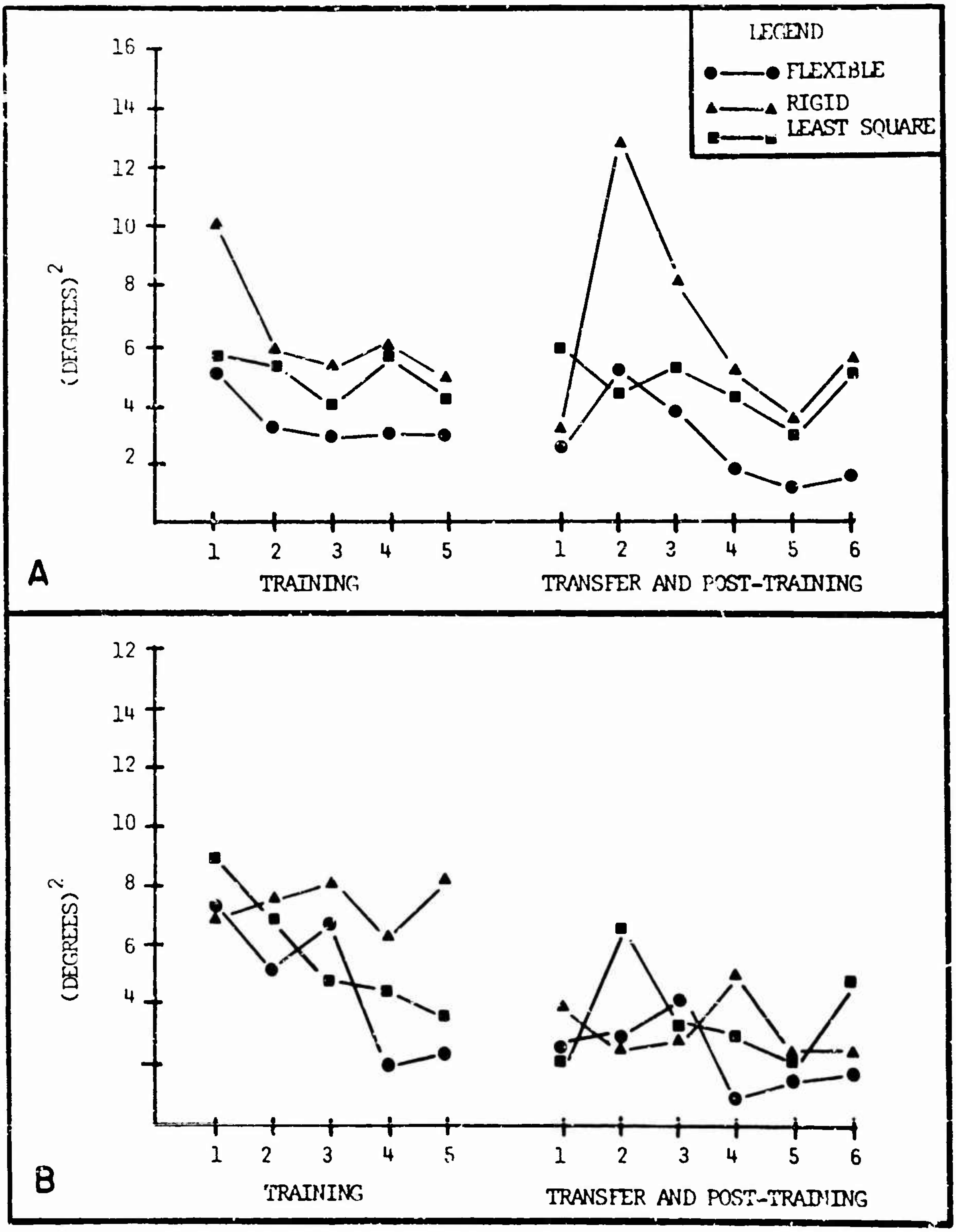

Figure 5. Average Performances of Experimental and Control Groups in Climbing Turn (A) and Level Turn (B) as Measured by Fore/Aft Stick Variance.

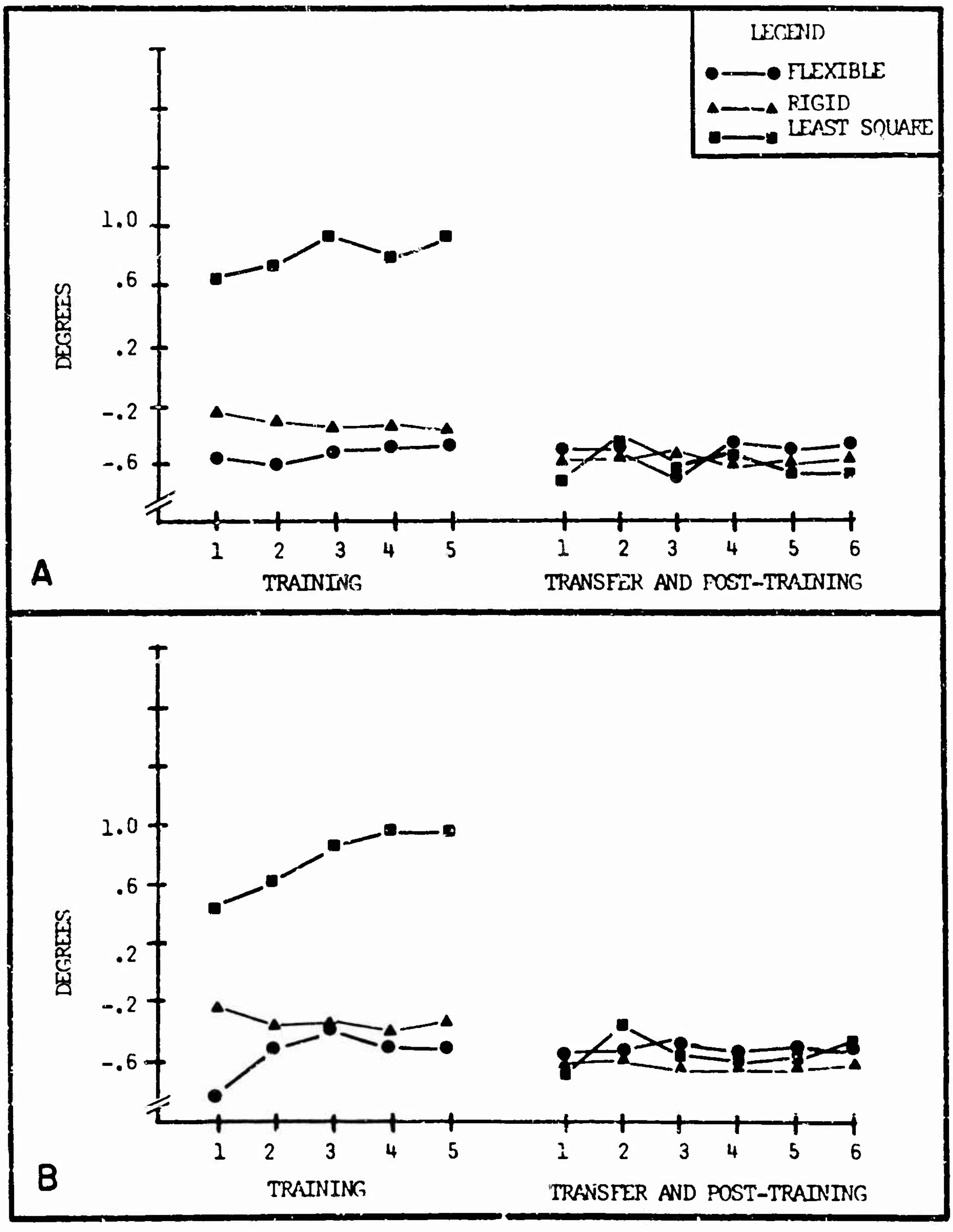

Figure 6. Average Performances of Experimental and Control Groups in Climbing Turn (A) and Level Turn (B) as Measured by Lateral Stick.

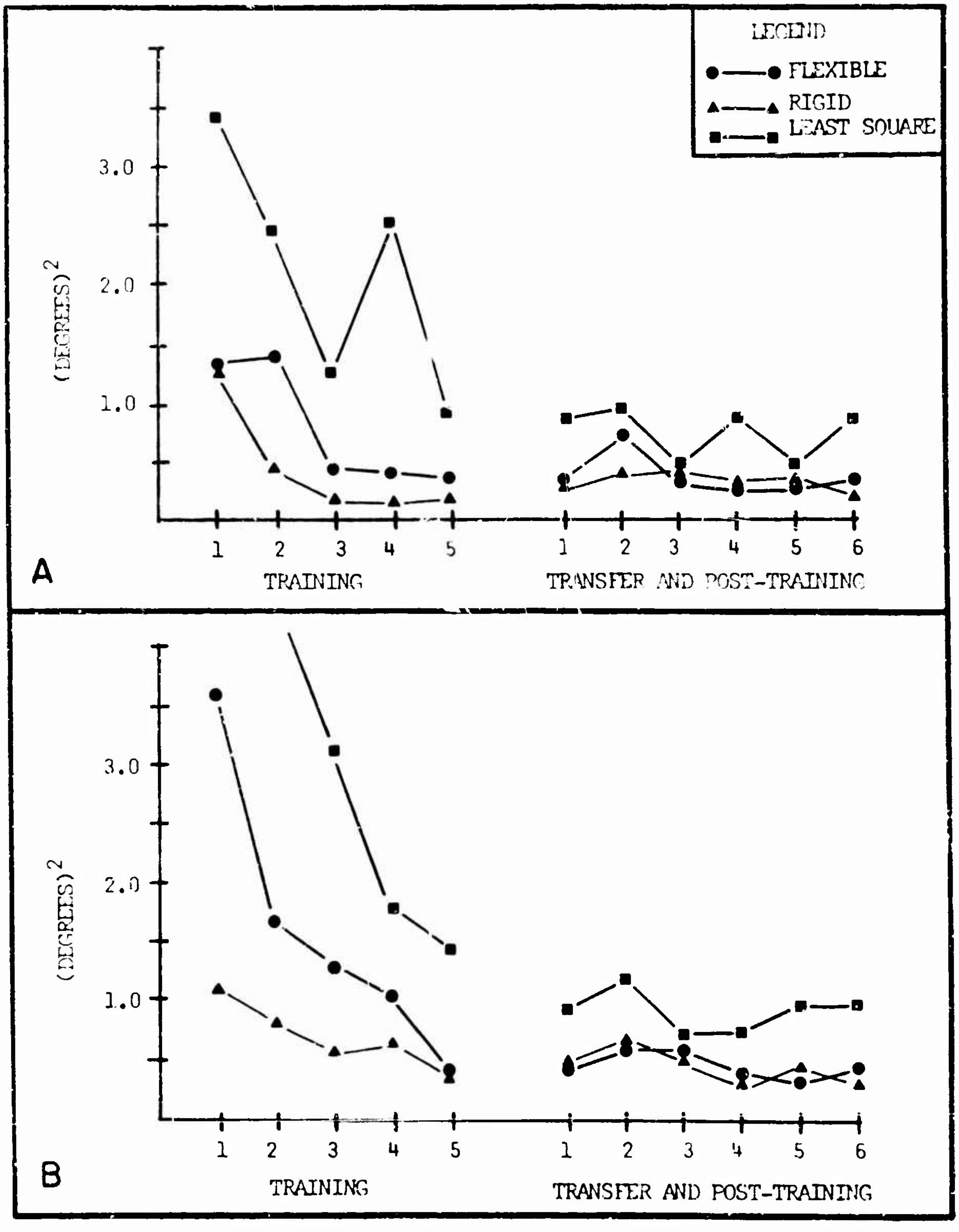

Figure 7. Average Performances of Experimental and Control Groups in Climbing Turn (A) and Level Turn (B) as Measured by Lateral Stick Variance.

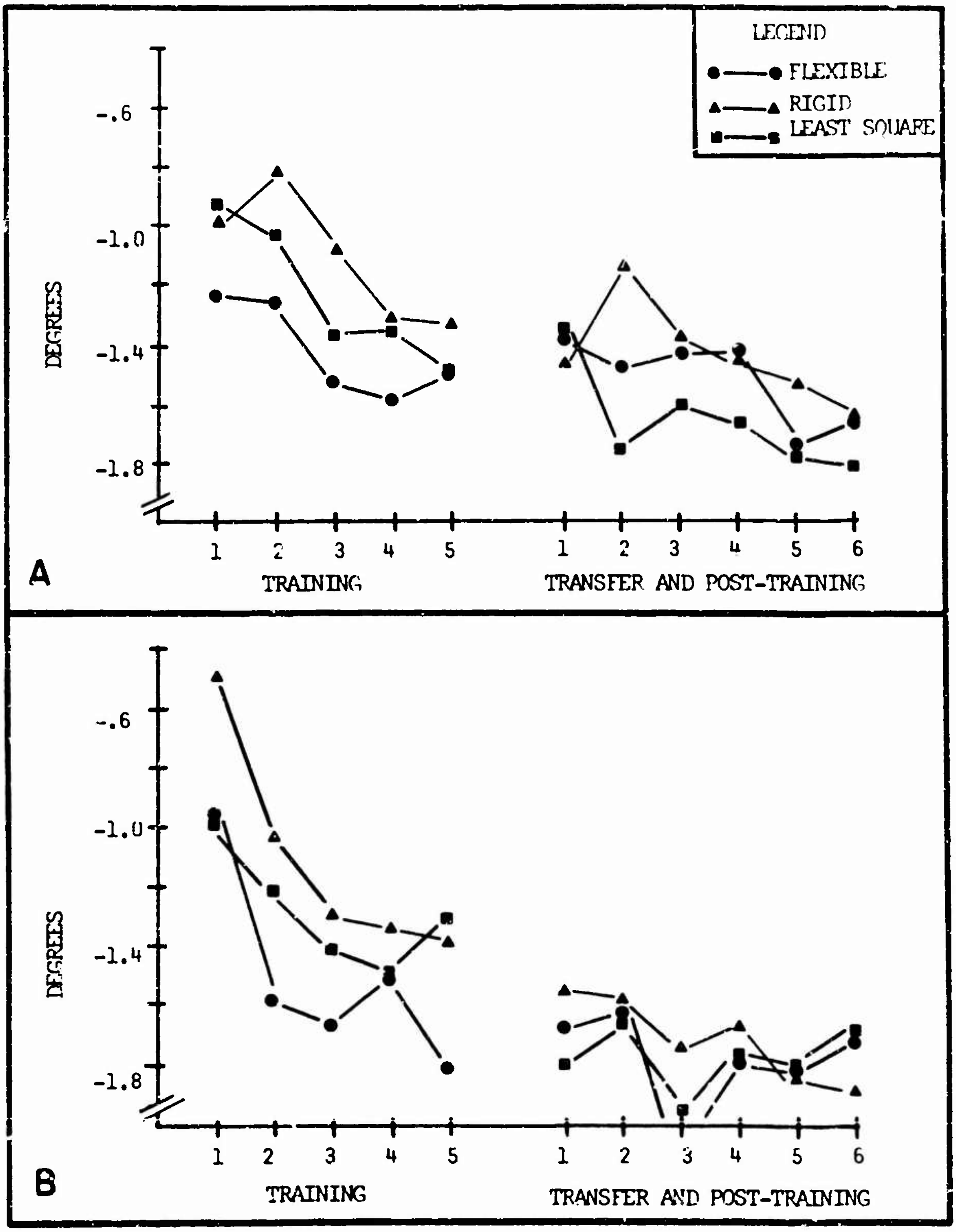

Figure 8. Average Performances of Experimental and Control Groups in Climbing Turn (A) and Level Turn (B) as Measured by Elevator Position.

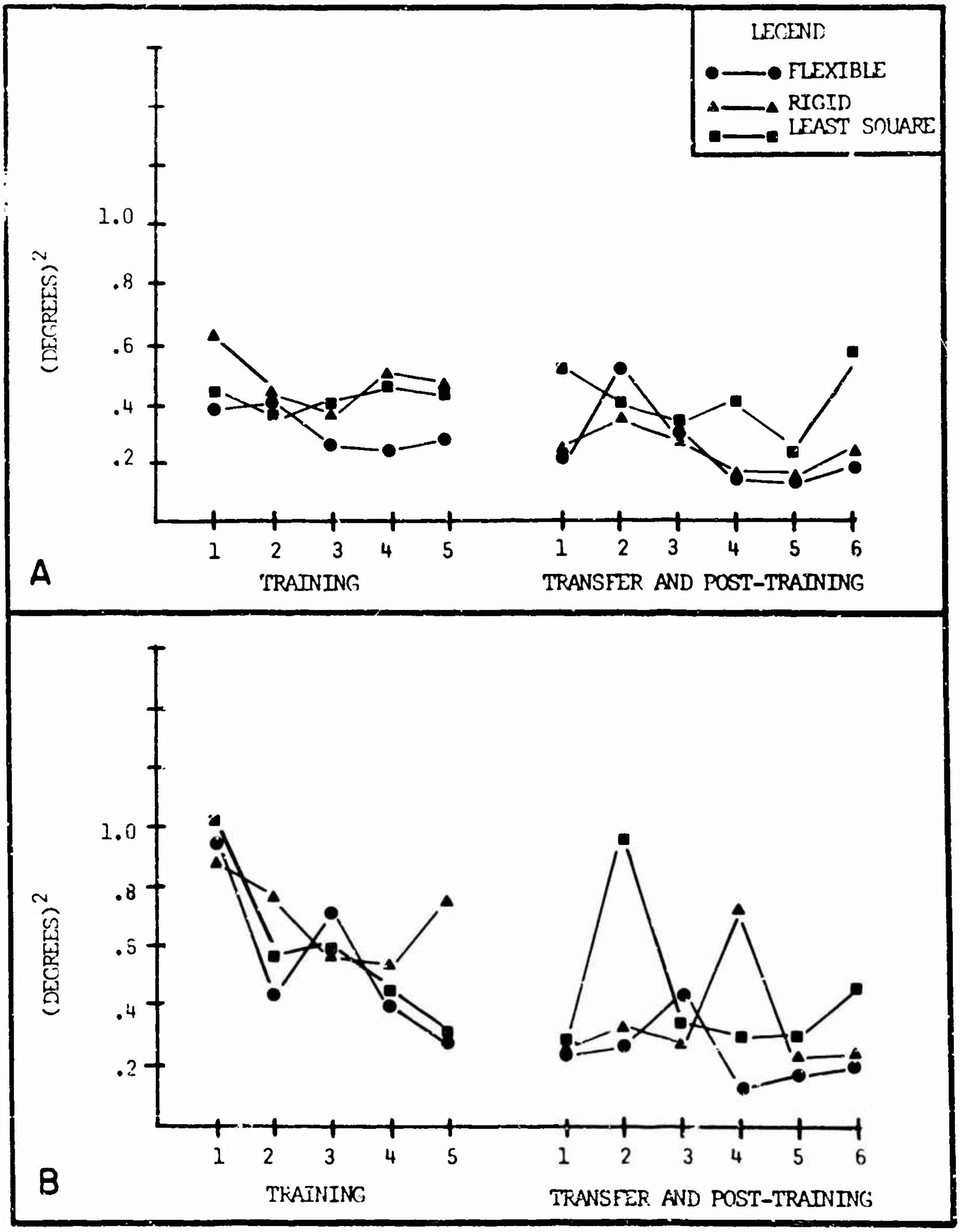

Figure 9. Average Performances of Experimental and Control Groups in Climbing Turn (A) and Level Turn (B) as Measured by Elevator Variance.

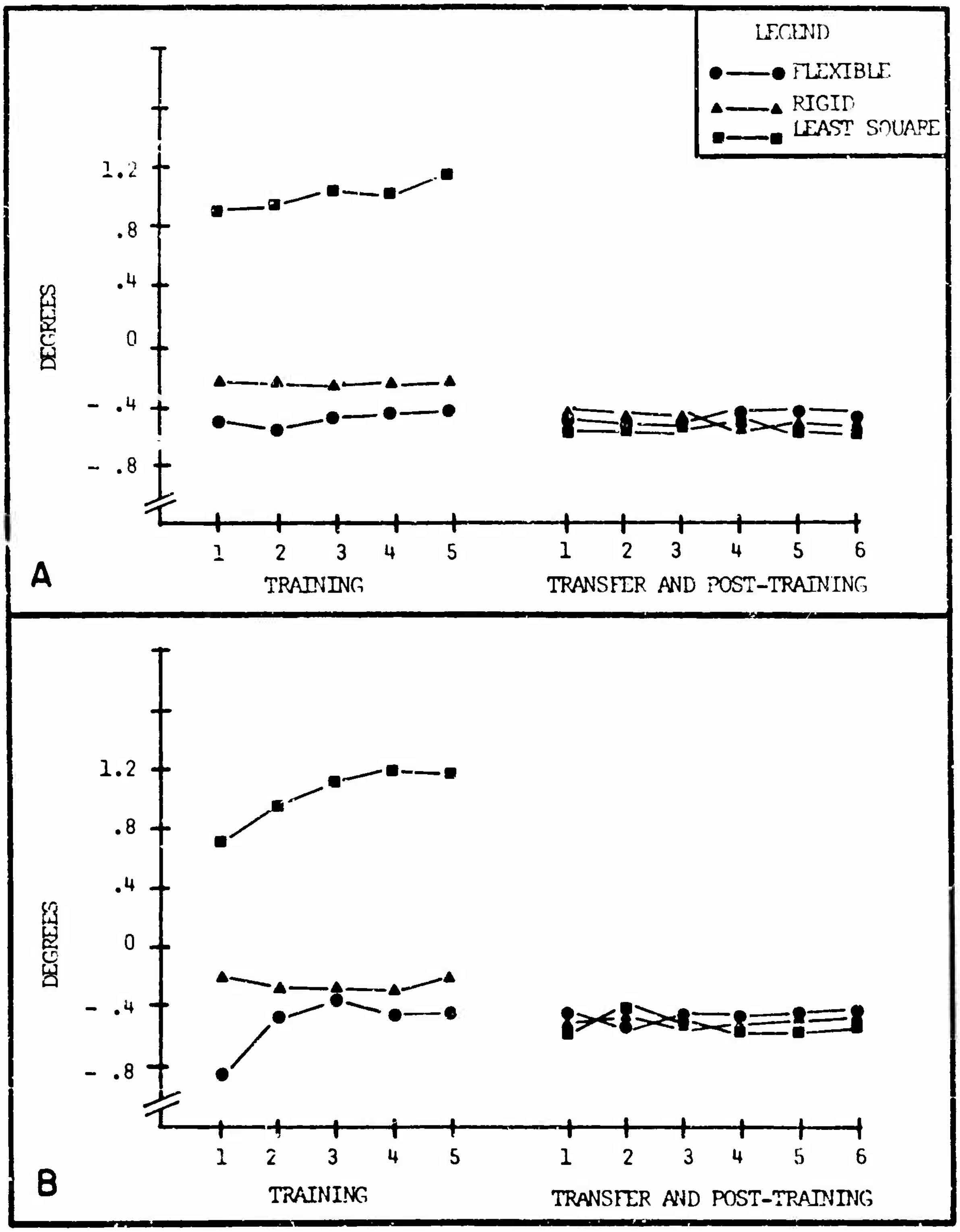

Figure 10. Average Performances of Experimental and Control Groups in Climbing Turn (A) and Level Turn (B) as Measured by Aileron Position.

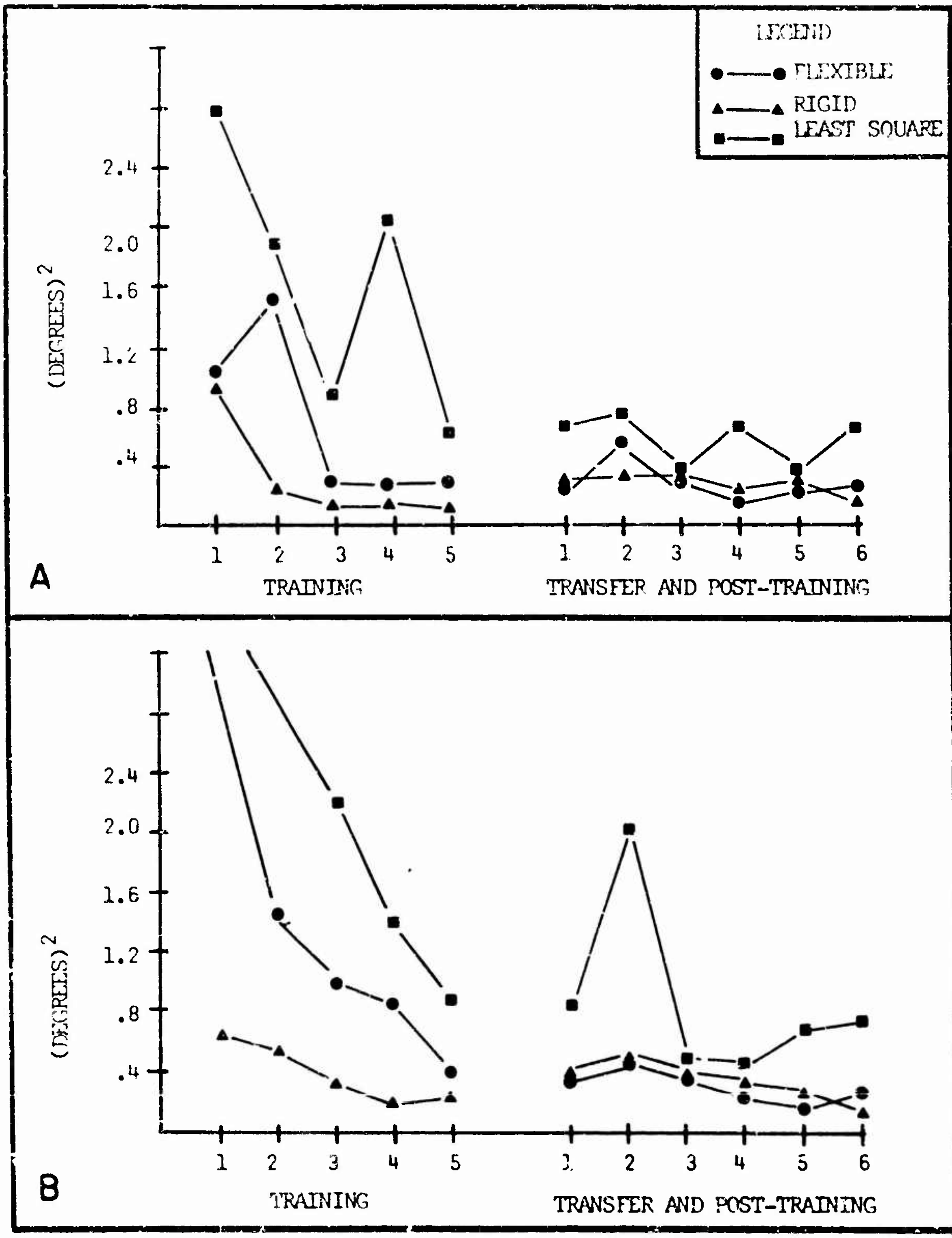

Figure 11. Average Performances of Experimental and Control Groups in Climbing Turn (A) and Level Turn (B) as Measured by Aileron Variance.

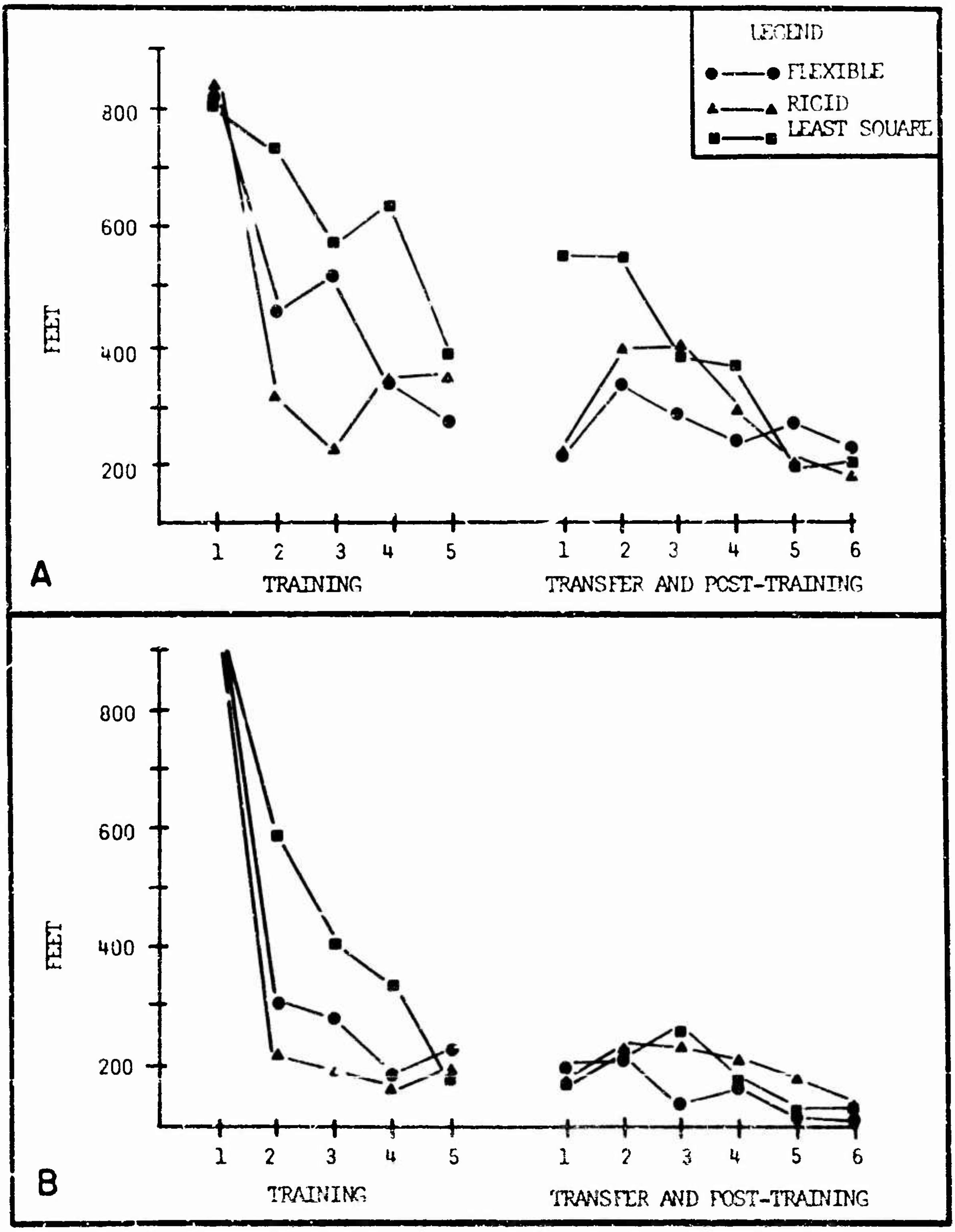

Figure 12. Average Performances of Experimental and Control Groups in Climbing Turn (A) and Level Turn (B) as Measured by Absolute Altitude Error.

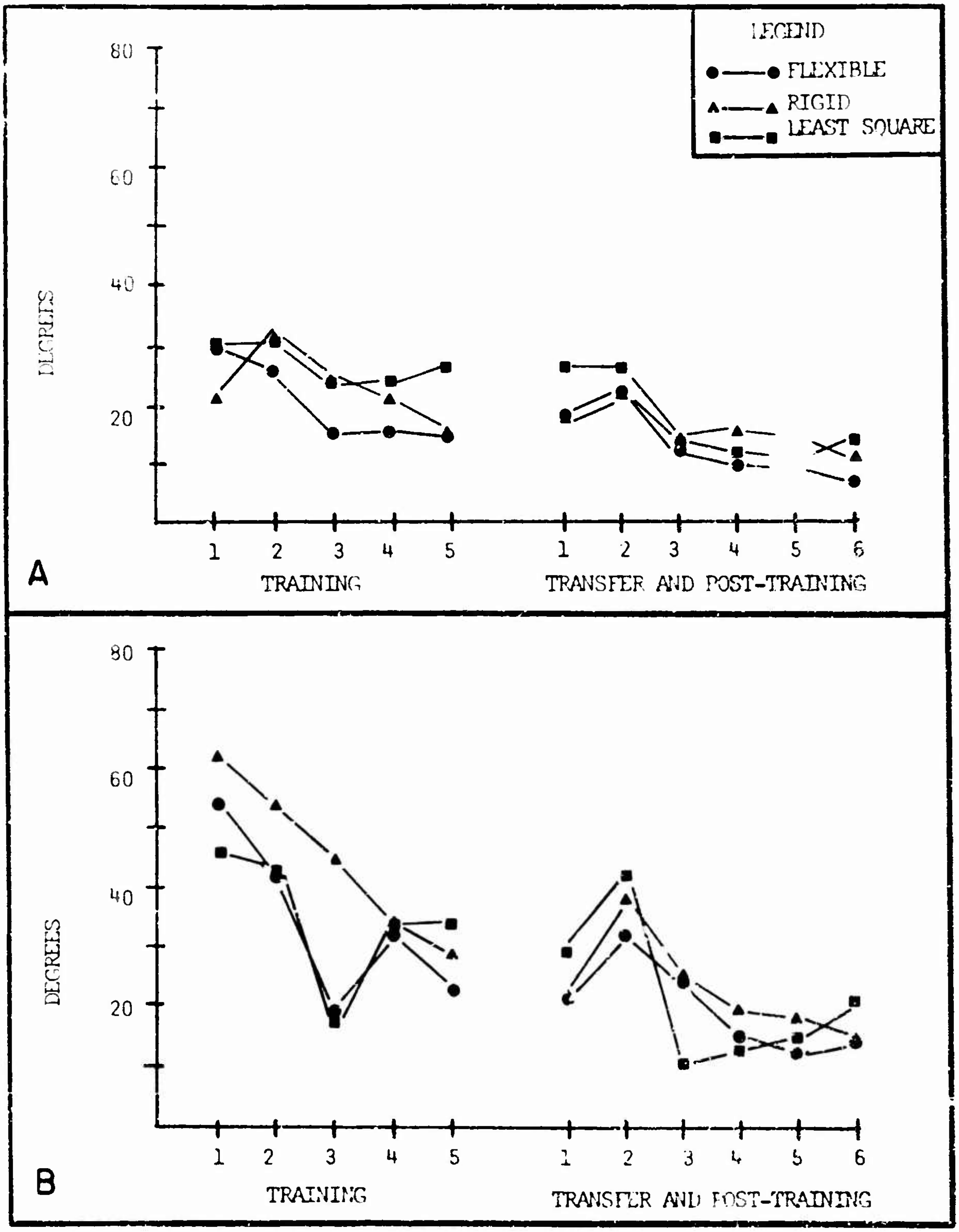

Figure 13. Average Performances of Experimental and Control Groups in Climbing Turn (A) and Level Turn (B) as Measured by Absolute Heading Error.

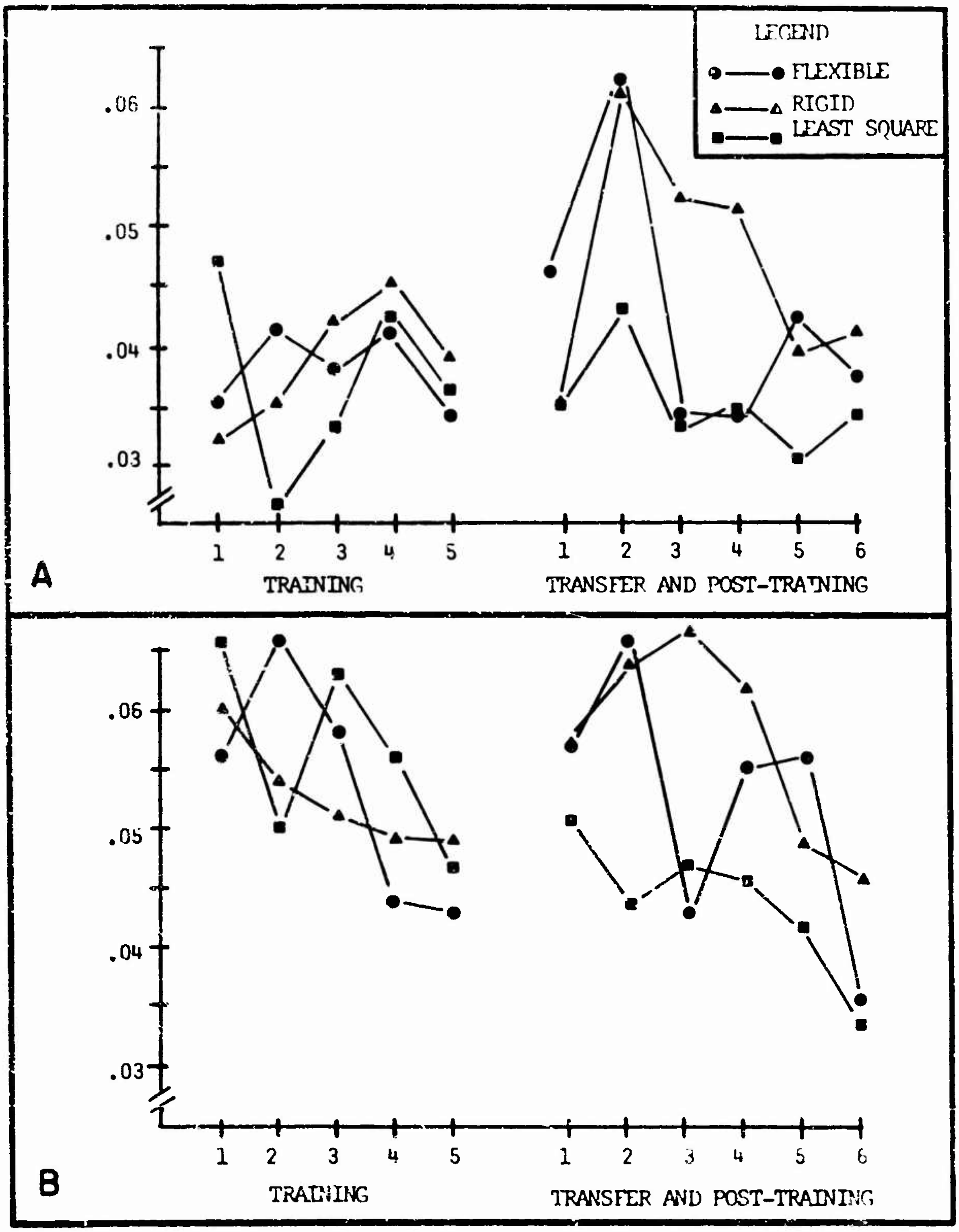

Figure 14. Average Performances of Experimental and Control Groups in Climbing Turn (A) and Level Turn (B) as Measured by Absolute Mach Error.

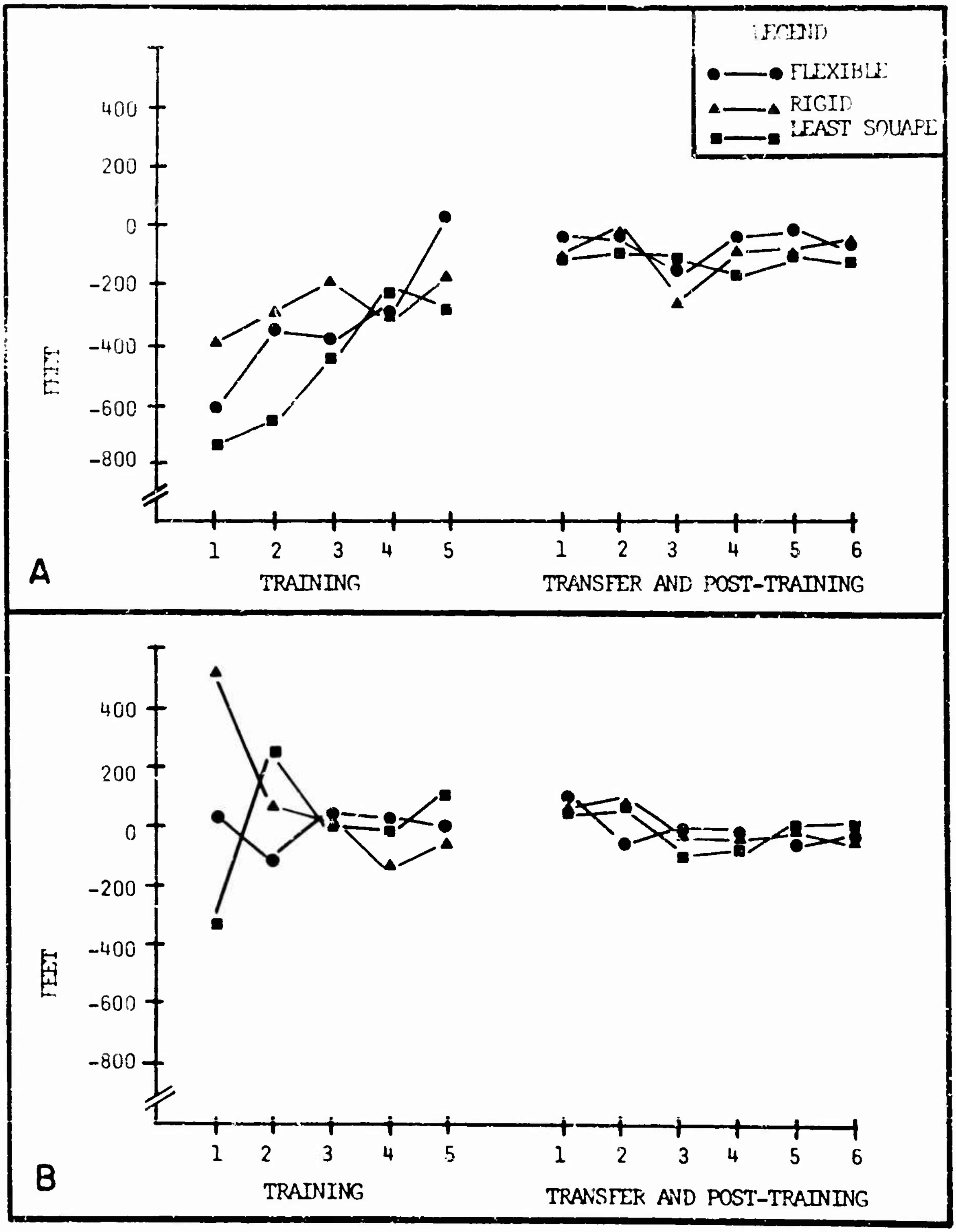

Figure 15. Average Performances of Experimental and Control Groups in Climbing Turn (A) and Level Turn (B) as Measured by Algebraic Altitude Error.

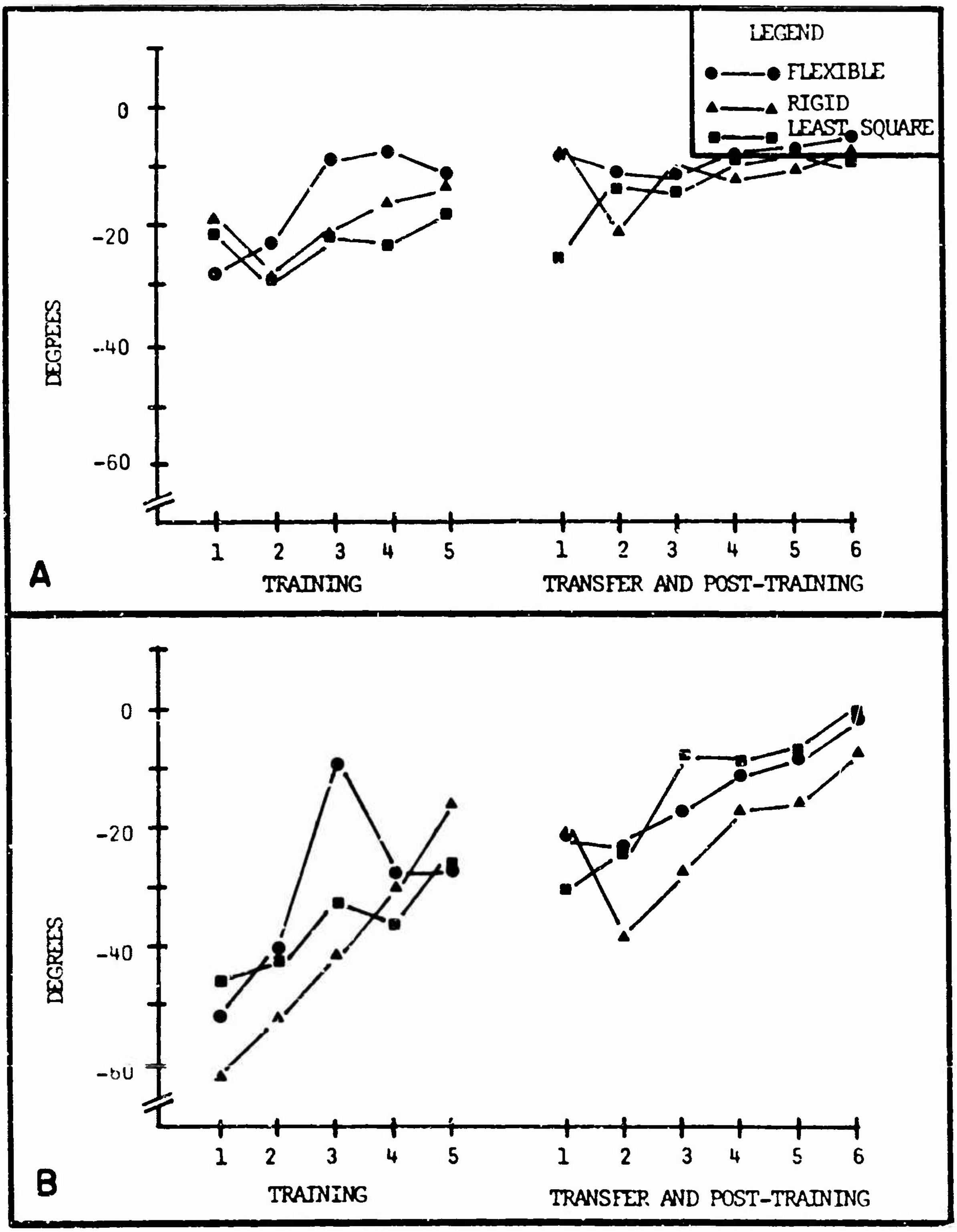

Figure 16. Average Performances of Experimental and Control Groups in Climbing Turn (A) and Level Turn (B) as Measured by Algebraic Heading Error.

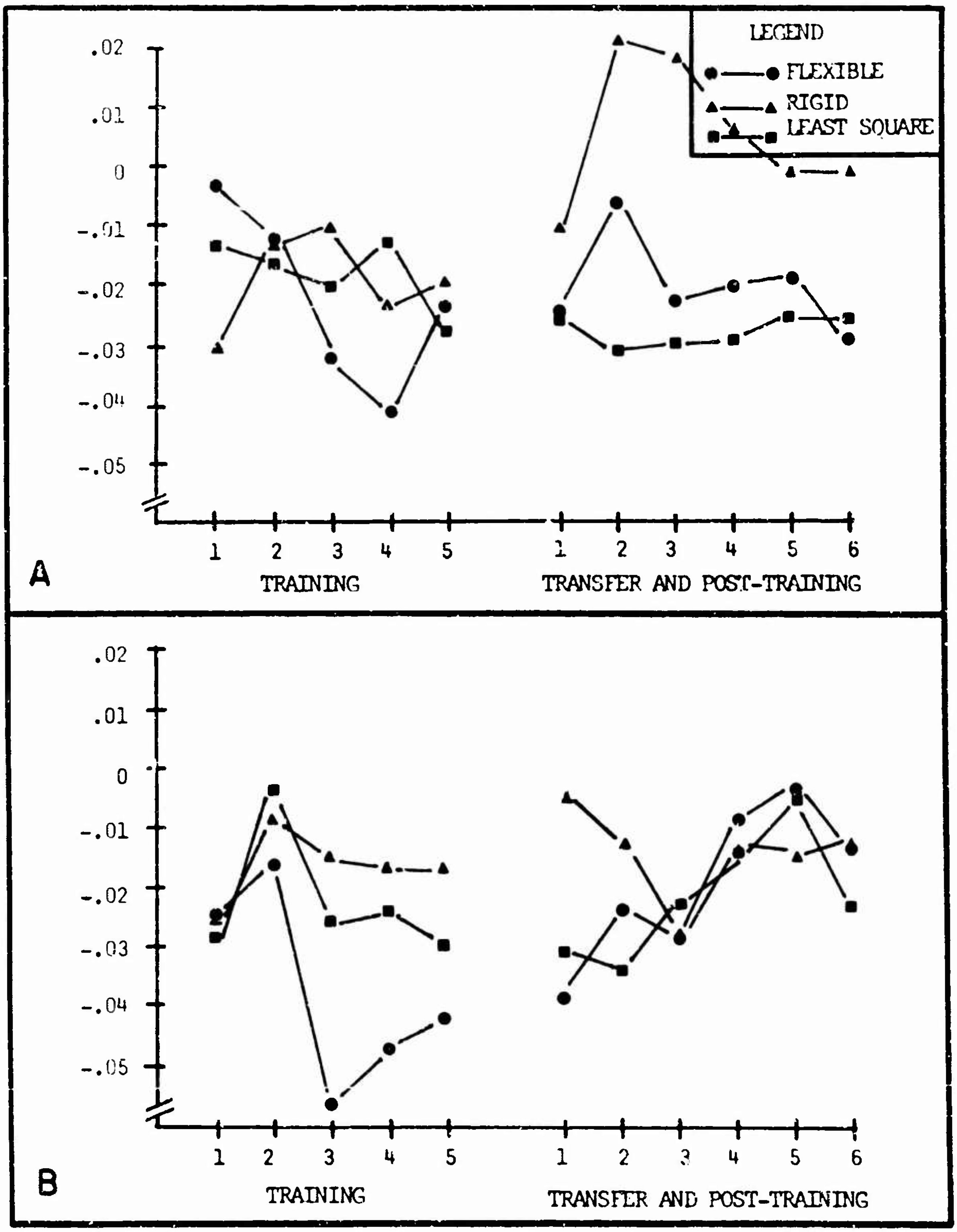

Figure 17. Average Performances of Experimental and Control Groups in Climbing Turn (A) and Level Turn (B) as Measured by Algebraic Mach Error.

Table 2

Sign Test Comparisons Between Mean Performances of Experimental and Control Groups During Training and Post-Training Trials

Comparison	Parameter	Training C-Turn	Training L-Turn	Post-Training C-Turn	Post-Training L-Turn
Rigid and Flexible Groups	Altitude Error	.754	.344	.754	.999
	Heading Error	.344	.180	.110	.110
	Mach Error	.180	.344	.344	.344
	Fore/Aft Stick	.022*	.022*	.002*	.344
	Lateral Stick	.002*	.002*	.180	.180
	Aileron Deflection	.002*	.002*	.999	.290
	Elevator Deflection	.002*	.002*	.508	.754
	Fore/Aft Stick Var.	.022**	.110	.002**	.344
	Lateral Stick Var.	.022*	.022*	.999	.999
	Aileron Deflection Var.	.022*	.022*	.999	.999
	Elevator Deflection Var.	.022**	.110	.999	.754
Least Sqrs. and Flexible Groups	Altitude Error	.110	.344	.754	.344
	Heading Error	.022**	.344	.754	.754
	Mach Error	.120	.344	.040*	.180
	Fore/Aft Stick	.022*	.022*	.110	.110
	Lateral Stick	.002**	.022**	.180	.754
	Aileron Deflection	.002**	.022**	.180	.999
	Elevator Deflection	.022*	.022*	.022**	.344
	Fore/Aft Stick Var.	.040**	.022**	.040**	.022**
	Lateral Stick Var.	.022**	.002**	.022**	.002**
	Aileron Deflection Var.	.002**	.022**	.040**	.002**
	Elevator Deflection Var.	.022*	.110	.110**	.022**

* Exceeds .05 level of significance; flexible group performances are larger.

** Exceeds .05 level of significance; flexible group performances are smaller.

Table 3

Comparisons Between Average Performances of Experimental Group (Rigid Data) Transfer Trials with Control Group (Flexible Data) on Comparable Trials

(1) Phase	(2) Parameter	(3) Control Group (C)	(4) Expermt. Group (E)	(5) Ratio E/C	(6) Prob.
	Altitude Error	208	213	1.02	.50
	Heading Error	17.5	16.8	.96	.45
	Mach Error	.043	.035	.81	.45
	Fore/Aft Stick	- 8.15	- 6.78	.83	.45
	Lateral Stick	- .51	- .57	1.12	.35
	Aileron Deflection	- .48	- .46	.96	.45
Climbing Turn	Elevator Deflection	- 1.30	- 1.39	1.07	.40
	Fore/Aft Stick Var.	2.5	3.1	1.24	.30
	Lateral Stick Var.	.37	.37	1.00	.50
	Aileron Deflection Var.	.23	.28	1.22	.30
	Elevator Deflection Var.	.23	.24	1.04	.45
	Altitude Error	201	180	.89	.45
	Heading Error	21.1	22.2	1.05	.45
	Mach Error	.057	.057	1.00	.50
	Fore/Aft Stick	- 8.28	- 5.93	.72	.40
	Lateral Stick	- .56	- .60	1.07	.40
	Aileron Deflection	- .47	- .49	1.04	.45
Level Turn	Elevator Deflection	- 1.56	- 1.44	.92	.45
	Fore/Aft Stick Var.	2.6	4.0	1.54	.20
	Lateral Stick Var.	.43	.50	1.16	.35
	Aileron Deflection Var.	.37	.40	1.08	.40
	Elevator Deflection Var.	.25	.27	1.08	.40

* Exceeds .05 Significance Level

Table 4

Comparisons Between Average Performances of Experimental Group (Least Squares) Transfer Trials with Control Group (Flexible Data) on Comparable Trials

(1) Phase	(2) Parameter	(3) Control Group (C)	(4) Expermt. Group (E)	(5) Ratio E/C	(6) Prob.
Climbing Turn	Altitude Error	208	541	2.60	.02 *
	Heading Error	17.5	25.2	1.44	.20
	Mach Error	.043	.035	.81	.45
	Fore/Aft Stick	- 8.15	- 6.86	.84	.45
	Lateral Stick	- .51	- .70	1.37	.25
	Aileron Deflection	- .48	- .53	1.10	.40
	Elevator Deflection	- 1.30	- 1.27	.98	.50
	Fore/Aft Stick Var.	2.50	5.90	2.36	.03 *
	Lateral Stick Var.	.37	.85	2.30	.03 *
	Aileron Deflection Var.	.23	.64	2.78	.02 *
	Elevator Deflection Var.	.23	.52	2.26	.04 *
Level Turn	Altitude Error	201	176	.87	.45
	Heading Error	21.1	29.0	1.37	.25
	Mach Error	.057	.051	.89	.45
	Fore/Aft Stick	- 8.28	- 8.17	.99	.50
	Lateral Stick	- .56	- .63	1.12	.35
	Aileron Deflection	- .47	- .49	1.04	.45
	Elevator Deflection	- 1.56	- 1.68	1.08	.40
	Fore/Aft Stick Var.	2.60	2.50	.96	.45
	Lateral Stick Var.	.43	.93	2.16	.05 *
	Aileron Deflection Var.	.37	.88	2.38	.04 *
	Elevator Deflection Var.	.25	.29	1.16	.35

* Exceeds .05 Significance Level

Table 5

Comparisons Between Average Performance of Experimental Group (Rigid Data) on Post-Training Trials and Control Group (Flexible Data) on Comparable Trials

(1) Phase	(2) Parameter	(3) Control Group (C)	(4) Expermt. Group (E)	(5) Ratio E/C	(6) Prob.
Rigid and Flexible Groups	Altitude Error	243	184	.76	.40
	Heading Error	8.0	12.2	1.52	.20
	Mach Error	.039	.040	1.02	.50
	Fore/Aft Stick	- 8.79	- 6.74	.77	.40
	Lateral Stick	- .49	- .57	1.16	.35
	Aileron Deflection	- .47	- .48	1.02	.50
	Elevator Deflection	- 1.62	- 1.51	.93	.45
	Fore/Aft Stick Var.	1.4	4.5	3.21	.01 *
	Lateral Stick Var.	.31	.27	.87	.45
	Aileron Deflection Var.	.22	.19	.86	.45
	Elevator Deflection Var.	.16	.19	1.19	.35
Least Sqrs. and Flexible Groups	Altitude Error	112	109	.97	.45
	Heading Error	12.9	15.9	1.23	.30
	Mach Error	.046	.047	1.02	.50
	Fore/Aft Stick	- 8.73	- 7.52	.86	.45
	Lateral Stick	- .52	- .60	1.15	.35
	Aileron Deflection	- .47	- .49	1.04	.45
	Elevator Deflection	- 1.67	- 1.76	1.05	.45
	Fore/Aft Stick Var.	1.7	2.5	1.47	.20
	Lateral Stick Var.	.35	.37	1.06	.40
	Aileron Deflection Var.	.24	.23	.96	.45
	Elevator Deflection Var.	.20	.24	1.20	.30

* Exceeds .05 Significance Level

Table 6

Comparisons Between Average Performances of Experimental Group (Least Squares Data) on Post-Training Trials and Control Group (Flexible Data) on Comparable Trials

(1) Phase	(2) Parameter	(3) Control Group (C)	(4) Expermt. Group (E)	(5) Ratio E/C	(6) Prob.
Rigid and Flexible Groups	Altitude Error	243	197	.81	.45
	Heading Error	8.0	11.8	1.47	.20
	Mach Error	.039	.032	.82	.45
	Fore/Aft Stick	- 8.79	- 7.90	.90	.45
	Lateral Stick	- .49	- .59	1.20	.30
	Aileron Deflection	- .47	- .54	1.15	.35
	Elevator Deflection	- 1.62	- 1.71	1.05	.45
	Fore/Aft Stick Var.	1.40	3.90	2.78	.02 *
	Lateral Stick Var.	.31	.66	2.13	.05 *
	Aileron Deflection Var.	.22	.48	2.18	.05 *
	Elevator Deflection Var.	.16	.40	2.50	.02 *
Least Sqrs. and Flexible Groups	Altitude Error	112	168	1.50	.20
	Heading Error	12.9	17.8	1.38	.25
	Mach Error	.046	.038	.83	.45
	Fore/Aft Stick	- 8.73	- 7.54	.86	.45
	Lateral Stick	- .52	- .55	1.06	.40
	Aileron Deflection	- .47	- .51	1.08	.40
	Elevator Deflection	- 1.67	- 1.65	.99	.50
	Fore/Aft Stick Var.	1.70	3.70	2.18	.05 *
	Lateral Stick Var.	.35	.93	2.66	.02 *
	Aileron Deflection Var.	.24	.73	3.04	.02 *
	Elevator Deflection Var.	.20	.44	2.20	.05 *

* Exceeds .05 Significance Level

(1) Well defined relationships between OFT system responses, control inputs by the pilot and deviations from programmed flight paths (i.e., error) exist for any and all conditions of simulation fidelity. Under high fidelity simulation, these relationships correspond closely to those for a real aircraft system.

(2) A change in simulation fidelity can potentially change these relationships in an OFT.

(3) As these relationships are changed, then differential control strategies will likely be learned by pilots during practice in the OFT.

(4) The effects of these differential control strategies on transfer to high fidelity simulation are unknown.

On the basis of these conceptual guidelines, attention will be given in the remaining portions of this section to a discussion: (1) of OFT system changes resulting from varying simulation fidelity by altering the aerodynamic coefficients; (2) of the effects of these variations upon control strategies of the pilot groups during practice trials; and (3) of how these particular control strategies affected pilot performance during the transfer task and subsequent post-training trials.

4.1 SYSTEM CHANGES

Interpreting the study results begins properly with gaining some understanding of the system changes introduced into the OFT when the aerodynamic coefficients were altered. Table 7 and 8, pages 36 and 37, show the percentage deviations for some of the more significant parameters in the longtiduinal and lateral modes respectively. These percentages represent each of the experimental conditions deviations from aeroelastic aerodynamic simulation fidelity. The parameters in each case illustrate the variation in open loop characteristics of the aircraft, i.e., without either the pilot or the stability augmentation system. The stability augmentation system, as with any feedback control system, will tend to reduce variation of the parameters inside the control loop. Some understanding of the magnitude of this reduction can be gained from Table 7, Page 36, by comparing the variation of the open loop short period natural frequency, $f_{sp(O.L.)}$, with the variation of the closed loop short period natural frequency, $f_{sp(C.L.)}$. When the loop is open, the percentage variation is 16.7%, but when the augmentation loop is closed, this variation is reduced to 12%. A more complete discussion of changes in the OFT system which resulted by varying the aerodynamic coefficients is available in NAVTRADEVCEN 1889-1 (Ellis, et. al., 1967) and, therefore, will not be repeated here.

An important question now is: What do these changes mean with respect to the manner in which the pilot participants controlled the UDOFTT during the simulated maneuvers? Whether or not these system changes do in fact differentially affect performance during the practice trials is discussed in the following paragraphs.

Table 7

Percentage Changes in Longitudinal Parameters

Parameters	Rigid	Least Squares
M_{α}	+ 16.5%	- 30.75%
$M_{\delta_{is}}$	+ 20.0%	- 8.3 %
Z_w	+ 7.5%	- 10.0%
M_q	+ 22.0%	- 8.0 %
* $\left[\dfrac{q_1}{\delta_{is}}\right]_{ss} = \dfrac{M_{\delta_{is}}\ Z_w}{M_{\alpha}}$	+ 10.5%	+ 18.5 %
f_{sp} (O.L.)	+ 8.0%	- 16.7 %
f_{sp} (C.L.)	+ 6.0%	- 12.0 %

* Pitch rate change per unit elevator deflection in the steady state.

Table 8

Percentage Changes in Lateral Parameters

N_β	+ 72%	- 30.7%
L_p	+ 27%	+ 7 %
$Y_v + N_r$	+ 106%	+ 3 %
L_{δ_A}	+ 125%	+ 53 %
* $\left\lvert \frac{p}{\delta_A} \right\rvert_{ss} = \frac{L_{\delta_A}}{L_p}$	+ 50%	+ 27.5%
$\lvert \phi/\beta \rvert$	- 41.8%	+ 17.6%
ζ_{DR}	+ 57%	+ 24 %
f_{DR}	+ 35%	- 19.5%
τ_p	- 27.5%	- 21.8%
τ_s	- 1.5%	- 20 %

* Roll rate per unit aileron deflection in the steady state

4.2 CONTROL STRATEGY LEARNING

A pilot's control strategy is generally conceived of as a pattern of control movements including direction, rate and so forth fashioned to maintain an aircraft within desired limits. The study parameters used to measure control strategies of the pilot-participants during the simulated maneuvers were control stick deviations from a neutral stick position. Both fore/aft and lateral stick deviations were measured in terms of central tendency and variance scores and Figures 4-7, Pages 16 - 19, depict pilot performance changes across trials as measured by these control strategy parameters. Correlates of these parameters are plotted in Figures 8-11, Pages 20-23. In the real aircraft, these latter correlates are surface measures which in addition to stick variation include variations in the trim and stability augmentation systems.

Two things are important in these figures. First of all, plots of the pilots' stick inputs across trials generally depict learning curve characteristics, i.e., within limits, these plots are monotonic, asymptotic and negatively accelerated in nature. This finding lends support to the conclusion that deviation scores decreased during training trials as a result of some kind of learning. Since these pilots had no previous jet experience, it is assumed that during these trials they developed control strategies for flying the jet simulator. Of course, the levels of sophistication of these strategies are difficult to precisely specify, but in the present study it is the presence of control strategy learning that is important not its precise description.

Further evidence of learning is found in plots of the system output parameters (Altitude, Heading and Mach) closely associated with the pilots' stick inputs. Since these were scored in terms of deviations from a programmed flight path, one would expect the pilots to become more proficient with each training trial if they were learning effective control strategies. These figures reveal as expected a general decrease in altitude, heading and mach errors during training trials. One additional note of explanation about these latter figures. Figures 12-14, pages 24 - 26, are plots of absolute errors which provide an understanding of the magnitudes of pilot errors. Figures 15-17, Pages 27 - 29, on the other hand, are plots of algebraic errors which provide insight into the direction of the pilots' errors, i.e., whether or not the pilots are ahead or behind the programmed flight maneuver which they were flying.

A second aspect worth noting in Figures 4-7 , Pages 16 - 19, is the apparent discrepancies in the amounts and variabilities of the pilots' stick inputs when the Experimental Groups are compared with the Control Group. In this respect, these figures generally reveal that pilots in the Control Group made larger inputs, but pilots in the Experimental Groups exhibited more input variability. Since the consistency of these discrepancies across training trials is

statistically significant (See Table 2, Page 30) it must be concluded that the pilot groups were required to develop, at least to some extent, different control strategies in order to fly the jet simulator under varying conditions of simulation fidelity.

It can be seen by re-examining the system output parameters in Figures 12-14, Pages 24 - 26, that discrepancies between the pilot groups as measured here are not as evident. As a matter of fact, Table 2, Page 30, reveals that discrepancies which are present are not statistically consistent in one direction or the other. Essentially, this means that although the pilots in their respective groups developed different control strategies, they managed to fly the UDOFTT under varying conditions of simulation fidelity within similar limits.

Summarizing to this point, the data clearly indicate that: (1) Each pilot-group received training on different conditions of simulation fidelity; (2) Proper management of each condition of simulation fidelity required the pilot-groups to develop different control strategies; and (3) Despite differences in simulation fidelity, the pilot-groups were able to maintain the UDOFTT within similar flight limits during training trials. The effects of these types of training upon the transfer task are discussed in paragraphs to follow.

4.3 TRANSFER TASK PERFORMANCE

Does practice on degraded conditions of simulation fidelity as described herein affect transfer to conditions of high simulation fidelity? It was hypothesized in earlier sections of this report that training of this nature could serve as an effective basis for transfer. To resolve this question and evaluate the study hypothesis, it is necessary to examine Tables 3 and 4, pages 31 and 32 , which summarize the results of statistical comparisons made between Experimental and Control groups during transfer trials. Graphical representations of transfer task performance which provide a basis for visual comparisons of the pilot-groups are shown in the latter portions of Figures 4-17, pages 16-29.

Table 3, Page 31, shows summaries of comparisons made at transfer between pilots who received training trials on rigid data simulation and pilots who received training trials on flexible data simulation, i.e., the control condition. According to the data in this table, there are no statistically significant differences in either the system output parameters or the control strategy parameters. This finding supports the study hypothesis that non-jet experienced pilots can be trained on an OFT under simulator conditions degraded by rigid data in the aerodynamic equations and then effectively transferred to conditions of high simulation fidelity.

Summaries of transfer comparisons made between pilots who received training trials on least squares simulation and pilots in the Control Group are contained in Table 4, Page 32. With the exception of altitude error during the climbing portion of the experimental maneuver, there are no statistically significant differences among the system output parameters. In addition, comparisons of central tendency measures of control strategy parameters reveal no significant differences in pilot-group performances. The table does, however, show in a rather dramatic fashion that variance measures of control strategy are statistically different. Coupling this latter finding with the results of the system output comparisons leads to the conclusion that although the least squares pilots are able to fly the simulator within limits comparable with the Control Group, they must work harder (i.e., more stirring of the stick) to achieve this performance. If this is the case, then some doubt must of course be cast on the training utility of least squares conditions of simulation in an OFT.

One question arising at this point is: When training on two levels of simulator fidelity has led to the development of control strategies different from the Control Group, why does training on one level serve as an effective basis for transfer and the other does not? A logical answer, although it cannot be supported with the present study design, is that more commonality, i.e., common skill components, existed between the control strategies of the rigid-group pilots and the Control Group than between the least squares group and the Control. In this case, the greater commonality would led to better transfer. Another explanation following a similar line of reasoning might emphasize that differences at transfer resulted from discrepant experiences during training. A re-examination of Figures 7 and 11, Pages 19 and 23 which are plots of control strategy variability generally show that large variances are characteristic during training under least squares conditions of simulation.

An alternative explanation to either of the previous suggestions could rest with the <u>Effective Time Constant</u> hypothesis which postulates that pilot performance is dependent upon time and visual threshold relationships between control inputs and displayed outputs (Matheny and Wilkerson, 1965). As these relationships vary between conditions of training and transfer, it is anticipated that transfer performance would be degraded. This latter explanation has more potential utility in the design and use of an OFT.

4.4 POST-TRAINING PERFORMANCE

Post-training was provided for each of the pilot-groups in order to evaluate, at least within the context of the study conditions, the longer-term effects of training. Tables 5 and 6, Pages 33 and 34,

were prepared for this purpose. Table 5, Page 33, summarizes comparisons between pilots in the rigid group and pilots in the Control Group, and Table 6, Page 34, is a summary of comparisons between the least squares group and the Control Group. Essentially the data in these tables reveal that the long-term effects of training on rigid conditions remain positive, but that the differences present at transfer for the least squares group are still evident in these post-training comparisons. This latter finding further discourages least squares data in OFT training situations.

4.5 SUBJECTIVE EVALUATIVE DATA

In addition to objective measurements discussed in previous sections, subjective data were also obtained from the pilots. These data consisted: (1) of pilot ratings (See Appendix B, Page 51), and (2) of pilot de-briefing comments (See Appendix D, Page 58).

The pilot questionnaire employed in this study is composed of several items which require usees to make judgments about an aircraft simulator. The items are bi-polar in nature, and ratings, i.e., judgments, must be made along a ten category continuum. Proper use of a questionnaire of this nature requires a fairly large sample of pilots. Since the pilot samples were quite small in the present study, no attempt was made to statistically evaluate the resulting data.

Non-statistical evaluations were, however, performed. To understand these evaluations, additional background must be introduced.

(1) An engineering analysis of the changes in the flying qualities occurring as a result of varying the coefficients in the flight equations revealed several things regarding stability. The rigid simulation was the most stable system; the least squares simulation was the least stable, and the Flexible simulation was between the two. These findings have important implications from the standpoint of the simulator's handling qualities. Etkin (1959) presents data indicating that pilot preference in aircraft handling qualities is greater for those similar to the rigid simulation as defined in the present study; they care less for the handling qualities similar to those of the flexible simulation, and have the least preference for handling qualities like those of the least squares simulation.

(2) In line with the range of stability differences incurring in the study, an examination of the system output errors (See Figures 12-14, pages 24-26) generally reveal that the rigid simulation was the least difficult to fly; the least squares was the most difficult, and the flexible was in between the two.

With these two ideas in mind, it was postulated that if the pilots in the present study could really discern the various levels of simulation fidelity, then certain results would exist when questionnaire ratings made during training trials are compared with ratings made at transfer. For examples:

(1) Ratings of the pilots in the Control Group should change very little since they were "flying" the same conditions during both training and transfer.

(2) Ratings of pilots in the Rigid Group should change at transfer indicating less preference for the flexible simulation.

(3) Ratings of the pilots in the Least Squares Group should change at transfer indicating a preference for the Flexible simulation.

Table 9, Page 42, summarizes the results of making comparisons of the nature just described. The table is derived from comparisons between the questionnaires completed just prior to transfer and the questionnaires completed after transfer. In comparing these two situations, the pilots either gave the same rating (i.e., Column 1 - No Change), changed his rating to indicate less preferable simulation conditions (i.e., Column 2 - Change to Less Desirable), or changed his rating to indicate more desirable simulation conditions (i.e., Column 3 - Change to More Desirable).

Table 9

Actual Percentage of Responses to 30 Item Pilot Questionnaire and Expected Response Levels for Each of the Three Pilot-Groups

	(1) No Change		(2) Change to Less Desirable		(3) Change to More Desirable	
	Expected	Actual	Expected	Actual	Expected	Actual
Flex. Data	L	.36	S	.34	S	.30
Rigid Data	S	.39	L	.34	S	.27
Lst Sqrs. Data	S	.41	S	.30	L	.29

Expected percentages of changes in ratings from the training situation to the transfer task for each group have been expressed in columns, Expected, as either L (i.e., a large percentage) or S (i.e., a small percentage). These expected estimates are based upon the preceding discussions of the differences in stability and of the difficulties of "flying" the simulator. In this case, it is expected that the majority of the ratings for the Flexible Group would change very little; therefore, in Table 9, L (i.e., Large percentage)

has been placed in the No Change column and S (i.e., Small percentage of change) placed in the other columns. Since the expected change in the Rigid Group would be in the direction of less desirable, L has been placed in the column noted as Change to Less Desirable, and S placed in the remaining columns. Finally, the expected change in ratings for the Least Squares Group should be in the direction of more desirable; therefore L has been inserted in the Change to More Desirable column, and S inserted in the others.

Entries in the columns designated Actual contain the resulting percentages of changes taken from the questionnaires. In comparing the Actual and Expected columns, it can be seen that there is little or no correlation; therefore, it was concluded that the pilots could not discern the different levels of simulation fidelity under which they operated the UDOFTT.

Data from the pilot-ratings based upon comparisons of the questionnaires completed just prior to transfer with the questionnaires completed after post-training were not compiled. Since anytime from a week to a month may have elapsed between transfer trials and post-training trials, these ratings were considered to be of questionable value.

A review of the pilots de-briefing comments (See Appendix B, page 47) reveals that the pilots were more concerned with evaluating the Audio-Visual Device rather than the simulator. Other than complaints regarding certain design features of this device the pilots' comments were quite favorable.

5.0 CONCLUSIONS

The present study is an integral part of a larger research program conducted by Life Sciences, Inc. for the Naval Training Device Center. The general hypothesis is that in an OFT setting practice on restricted conditions of simulation fidelity defined within the aerodynamic equations of flight can serve as a basis for transfer to high fidelity conditions of simulated flight. The implication is that "high engineering fidelity" is not required in the design and development of an OFT. Although earlier studies in the program demonstrated the feasibility of the hypothesis with highly experienced jet pilots, the primary objective of the present study is to establish the validity of the hypothesis with pilot samples corresponding more to the types of pilots found in primary training.

5.1 STUDY FINDINGS

The following items represent findings based on the rationale and procedures employed in the planning and conduct of the present study and on the results of statistical tests applied to the study data:

(1) The use of aeroelastic equations simplified by rigid coefficients in OFT settings provides an effective training basis for subsequent transfer to high fidelity simulation. Data supporting this finding are evident at the outset of transfer, and in addition the effects of training on these conditions remain positive during subsequent post-evaluation trials.

(2) Using least squares approximations to the flexible coefficients in the aerodynamic equations during training in OFT settings does not appear to be feasible. The data show that although system outputs for the least squares and control group pilots are within similar limits, the least squares pilots show greater variability in their control inputs (i.e., more control stick movement). It seems that during training the least squares pilots develop a tendency for greater variability, and this disposition not only carries over into the transfer task but is also present during post-evaluation trials. Apparently, these pilots have to work harder to achieve the same objectives as the control pilots.

(3) The Audio-Visual Training Device is an appropriate vehicle for providing familiarization and practice in reading, interpreting and responding to aircraft flight instruments. The Device and its associated programs provided instrument-rated, non-jet-experienced pilots sufficient training for "flying" successfully the experimental maneuver in the UDOFTT.

5.2 STUDY IMPLICATIONS

Pilot training is, of course, a very broad field encompassing several spheres of interest pertaining to personnel, equipment and methods. To imply in this case that the present study findings have far reaching implications for pilot training in general is perhaps overstating the case. It does seem, however, that within the limitations of the program (see para. 2.1) the present study results have significant implications for at least three problem areas in the field of pilot training. The following items are brief discussions of these implications.

(1) Significant data has been provided from this study to assist in resolving the problem of transfer of training versus simulation fidelity of Operational Flight Trainers (OFT). The current practice in the design and development of an OFT is to emphasize the necessity and desirability of "high engineering fidelity", but the study results demonstrate that simulation fidelity can be degraded by using rigid coefficients in programmed flight equations and still be an effective condition for training. One can certainly infer from this finding that "high engineering fidelity" is not a necessity. Resolving the issue of desirability will depend upon other data regarding specific amounts of transfer of training, costs and subjective evaluations.

(2) Results from this study provide additional data for a growing research data base which supports enlarging the role of OFT's in operational flight training programs. In the past, the OFT has been principally employed as a procedures trainer in which highly experienced pilots are trained to pre-defined criterion levels. More recent data suggest broader uses for OFT's. Meyer and Flexman, et. al. (1967) have demonstrated that simulator time can be substituted for aircraft time in transitioning airline captains into the DC-8, and in preparing them to pass an FAA flight check. Although the role of the simulator in the Meyer and Flexman study goes beyond that of a procedures trainer, its demonstrated usefulness was limited to highly experienced airline pilots. Present study data suggest that an OFT can be used perhaps to train lesser skilled pilots in the execution of prescribed flight maneuvers. Although the pilots in this study were transferred to high fidelity simulator conditions, the proof of this suggestion would, of course, depend upon transferring them to a real aircraft as was the procedure used by Meyer, Flexman, et.al.(1967).

(3) Using rigid coefficients in the flight equations will serve to reduce the complexity of OFT/system computer operations. This reduction in complexity is accomplished by reducing the memory storage requirements for programming the equations of flight used in OFT simulations. A detailed discussion of the amount of savings in memory space is contained in a previous report (NAVTRADEVCEN 1889-1: Ellis, et. al., 1967).

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APPENDIX A

Audio-Visual Trainer

General - The audio-visual trainer is intended to provide instruction and practice in reading, interpreting and responding to aircraft flight instruments. As far as the current work, specifically, is concerned, the intent is to provide training for instrument-rated, non-jet-qualified pilots (principally light plane pilots) so that they may be able to successfully fly a maneuver in the UDOFTT after relatively little practice in the simulator itself. The training is accomplished by displaying a sequence of static instrument panel situations, depicting deviations from specified flight profiles, to which the trainee responds with the necessary corrective control movement using a miniaturized throttle or control stick. A programed instruction format is followed whereby the situations depicted in the instructional frames progress from easy to difficult in a sequence arranged to teach specific patterns of instrument checking and avoidance of common interpretive errors. For each frame, the trainee receives immediate confirmatory feedback if the correct response is given and an explanation (optional) of the correct response if an incorrect response is made. [The term "frame" is used here in the programed instruction sense meaning one unit of instruction, i.e., a display situation, with such associated commentary and opportunity to respond as may accompany it, constitutes one frame.]

Apparatus - The trainer is composed basically of a control console, tape recorder, slide projector, the subject's controls, a response indicator panel, and a rear projection screen. One channel of the tape recorder provides the audio portion for each frame while the other channel furnishes tone pulses to the control console to coordinate the operation of the equipment. Outputs from the control console operate the slide projector and shutter and display the subject's response on the response indicator panel (a row of lamps, one of which lights to show what response was made). The console also contains the circuitry to determine automatically whether the correct response was made, and if so, to turn on the correct response light and bypass the audio feedback to the subject's headphones. In addition, a .01 sec timer on the console indicates the subject's response latency. The subject's controls are attached to the front of the rear projection screen and at the top of the screen are the "get ready" and "correct" lamps. The controls are a two-position throttle, moved forward and aft from a neutral center position to indicate power changes and an eight position neutral center stick with a push button in the end of the stick. The stick is moved directly forward and aft, directly to either side, or diagonally in a combination movement, to indicate pitch and roll corrections. Only the stick or the throttle, not both, may be moved in response to a given frame. The push button on the stick is depressed if no correction is required. The controls record the direction of movement only, with no indication of magnitude, since control movements are sensed by switches.

Current Programs

Three programs are used in the "non-jet experienced pilots" study: 1) an initial orientation and level flight program administered prior to flying the matching maneuver and; 2) a 4000 ft. timed climb and descent program given just prior to; 3) two 360° timed level turns practiced before flying the study maneuver. The climb and turn programs provide separate practice on the two aspects of the climbing turn study maneuver. The speed-altitude regime for the three programs is the same as for the study maneuver - Mach 1.10 and 25,000 ft.

In all three programs, the combinations of instruments used to show deviations from the desired flight path were selected based upon eye movement studies of instrument references employed by experienced pilots flying various maneuvers. Thus, the frequency with which a particular combination of instruments depict an error is approximately that frequency at which the combination should be checked in actual flight. Since no data were available to suggest what error situations to use, the types and magnitudes of errors shown, and their frequency of occurence are derived from the investigators' piloting experience and knowledge of the piloting task.

Two aspects of each frame determine its order in the easy difficult progression of each program: 1) the control movement required, e.g., diagonal movements of the stick are more difficult, from an interpretive viewpoint, than direct fore-aft or side movements, and 2) the "agreement" of rate and position instruments, e.g., a descending-and-below-altitude condition. Also, common to all three programs is the use of prompting for those frames with which an initial group of subjects had difficulty. Each prompted frame is followed later in a given program by a similar, unprompted frame.

In the first program, which has 43 frames and requires about 30 min., the task is to make the one control input which will return the aircraft to level flight on heading at 045°, 25,000 ft., and Mach 1.10 from whatever condition is displayed on a given slide. The first two frames introduce the apparatus and program and permit a trial response. The next two frames are a test of initial proficiency which is followed by 13 frames illustrating use of the gyro horizon in conjunction with other instruments to determine the correct response.

In the first 5 of the 13 practice frames, the rate-of-climb instrument must be checked along with the gyro. Two of these frames are prompted and one enriched frame points out that the rate-of-climb indication will lag slightly behind the pitch angle indication. Two frames using the gyro and altimeter are followed by two frames combining the indications of the gyro, rate-of-climb, and altimeter (one frame of each pair is prompted). The last four frames, two of which are prompted, require reference to the gyro and heading indicator.

Duplicates of the preceding 13 frames are mixed among the following 22 frames, but no prompting is employed. Two of the 22 frames require a throttle adjustment and two other frames need no corrective input. The last four frames of the program are a final proficiency test and include duplicates of the two frames used in the initial test as a check for improved performance.

Response intervals are all 5 sec. except for the initial test (10 sec.), five exceptionally difficult frames (6, 7, or 8 sec., according to difficulty), and the final test (8 sec.)

If a subject responds incorrectly to 10 or more of the last 26 frames, he is given a second opportunity, following a short break, to practice the sequence again; this requires another 15 minutes. The criterion of 10 errors is based on the pre-testing of a preliminary group of subjects.

The second program begins with an introduction and because of the lengthy time interval between first and second programs, a review of the apparatus operation and another trial frame are included. The maneuver for the second program is a 2000 ft/min climb from 23,000 to 27,000 ft., followed immediately by a 2,000 ft/min descent back to 23,000. Mach 1.10 and a 045° heading are to be maintained throughout the maneuver.

Because use of the clock is being introduced in this program, the three frames following the two introductory frames provide an opportunity to practice using the clock as a reference. For this purpose, these frames depict a 2,000 ft/min descent from 25,000 to 24,000 ft. The next 12 frames cover the climb portion of the maneuver and are followed by the descent in 12 more frames. The clock shows 10 sec. after 6 o'clock in the first frame of the climb and is advanced 10 sec. in each succeeding frame.

In the 24 frames of the climb and descent there are four prompted frames, four frames requiring throttle adjustments and three frames which require no corrective input. The entire program of 29 frames is 20 min. in duration.

Upon completion of the second program, the trainee is given a short rest period before starting the third program. The first frame introduces the maneuver for the third program - a 2 min., 360° right turn followed immediately by a 2 min., 360° turn to the left. Throughout the maneuver a 3°/sec rate of turn is to be maintained while airspeed and altitude are to be held constant at Mach 1.10 and 25,000 ft. Conditions for the clock are the same as in the second program.

The right turn is completed in 12 frames and is followed by 12 frames for the left turn. Three frames are prompted, three require no corrective input, and no throttle adjustments are required. This program employs 25 frames and is completed in 15 min.

At the end of each of the programs, a brief, audio-only frame announces the end of the lesson and advises the subject to await further instructions or that instruction will continue following a short break. Thus, the complete sequence of three programs totals 100 frames and 65 minutes. A subject who misses 10 or more of the last 26 frames in the first program will have an additional 26 frames and 15 min. for a total of 126 frames and one hour and 20 min. of instruction.

APPENDIX B

Pilot Rating Scale

Instructions

1. Read each question carefully.

2. Place an "x" in the box which best describes your evaluation. Put only one "x" in any 10 point scale.

3. Consider only that specific aspect of the simulator described by the question.

4. Special Instructions:
   You will be asked to evaluate several aspects of the simulator without considering stick forces or characteristics of the trim system. <u>Specific instructions will be provided before each of these questions.</u>

5. Be sure to answer all questions.

6. Remember, judge each aspect of the simulator on its own merit.

Pilot ______________________ Date ______________________

Testing Occasion 1 2 3 4 5

1. How difficult was it to maintain the altitude program?

Exceptionally Easy	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	Exceptionally Hard

2. How much stick force was required to obtain changes in altitude?

A Great Deal of Force	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	Very Little Force

3. How does the simulator respond in pitch?

Extremely Fast	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	Extremely Slow

4. How much did the response of the pitch bar lag a stick input?

Very Little Lag	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	A Lot of Lag

5. How sensitive was the pitch response to a stick input?

Very Sensitive	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	Not Sensitive

Instructions for Item 6

DO NOT CONSIDER STICK FORCES OR UNIQUE CHARACTERISTICS OF THE TRIM SYSTEM IN MAKING THE FOLLOWING EVALUATION.

6. How much was it necessary to make fore and aft stick movements and/or elevator trim adjustments in order to maintain the required altitude program?

A Great Deal of Movement and/or Adjustment	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	Very Little Movement and/or Adjustment

7. How difficult was it to maintain the heading program?

Exceptionally Easy											Exceptionally Hard

8. How much lateral stick force was required to obtain changes in turn rate?

A Great Deal of Force											Very Little Force

9. How does the simulator respond in roll?

Extremely Fast											Extremely Slow

10. How sensitive was the roll response to a lateral stick input?

Very Sensitive											Not Sensitive

Instructions for Item 11

DO NOT CONSIDER STICK FORCES OR UNIQUE CHARACTERISTICS
OF THE TRIM SYSTEM IN MAKING THE FOLLOWING EVALUATION.

11. How much was it necessary to make lateral stick movements and/or aileron trim adjustments in order to maintain the required heading program?

A Great Deal of Movement and/or Adjustment											Very Little Movement and/or Adjustment

12. How much attention and correction were required to maintain the bank angle and heading program?

A Great Deal of Attention and Correction											Not Much Attention and Correction

13. How difficult was it to fly the required maneuver in the simulator?

Exceptionally Easy											Exceptionally Hard

14. With respect to maintaining the altitude program, how would you rate the simulator?

Extremely Satisfactory											Extremely Unsatisfactory

15. How would you rate the stick force necessary to obtain altitude changes?

Extremely Satisfactory											Extremely Unsatisfactory

16. How would you rate the speed of the pitch response of the simulator?

Extremely Satisfactory											Extremely Unsatisfactory

17. How would you rate the lag of the pitch bar to a stick input?

Extremely Satisfactory											Extremely Unsatisfactory

18. How would you rate the sensitivity of the pitch response to a stick input?

Extremely Satisfactory											Extremely Unsatisfactory

Item 19

DO NOT CONSIDER STICK FORCES OR UNIQUE CHARACTERISTICS
OF THE TRIM SYSTEM IN MAKING THE FOLLOWING EVALUATION

19. How would you rate the number of fore and aft stick movements and/or elevator trim adjustments necessary to maintain the required altitude program?

Extremely Satisfactory											Extremely Unsatisfactory

20. How would you rate the controllability of the simulator in maintaining altitude?

Extremely Satisfactory											Extremely Unsatisfactory

21. With respect to maintaining the heading program, how would you rate the simulator?

Extremely Satisfactory											Extremely Unsatisfactory

22. How would you rate the stick force necessary to change turn rate?

Extremely Satisfactory											Extremely Unsatisfactory

23. How would you rate the speed of the roll response of the simulator?

Extremely Satisfactory											Extremely Unsatisfactory

24. How would you rate the sensitivity of the roll response to a lateral stick input?

Extremely Satisfactory											Extremely Unsatisfactory

Instructions for Item 25

DO NOT CONSIDER STICK FORCES OR UNIQUE CHARACTERISTICS
OF THE TRIM SYSTEM IN MAKING THE FOLLOWING EVALUATION

25. How would you rate the number of lateral stick movements and/or aileron trim adjustments necessary to maintain the required heading program?

Extremely Satisfactory											Extremely Unsatisfactory

26. How would you rate the amount of attention and correction required to maintain the bank angle and heading program?

Extremely Satisfactory											Extremely Unsatisfactory

27. How would you rate the controllability of the simulator in maintaining heading?

Extremely Satisfactory											Extremely Unsatisfactory

Instructions for Item 28

INCLUDE UNIQUE CHARACTERISTICS OF THE TRIM SYSTEM IN MAKING THE FOLLOWING EVALUATION.

28. How would you rate the trim system of the simulator?

Extremely Satisfactory											Extremely Unsatisfactory

Instructions for Item 29

INCLUDE STICK FORCES IN MAKING THE FOLLOWING EVALUATION

29. How would you rate the stick with respect to breakout forces, feel, etc.

Extremely Satisfactory											Extremely Unsatisfactory

30. How would you rate the simulator as a whole?

Extremely Satisfactory											Extremely Unsatisfactory

APPENDIX C

Maneuver Briefing

The maneuver you are to fly will be a standard rate 360 degree turn with one minute of climb and one minute of maintaining a constant altitude during the turn. The simulator will be set with a heading of 0 degrees, 1.1 Mach and 24,000 feet of altitude. When the simulator is released into your control you will have 30 seconds of straight and level flight as warmup before starting a standard rate, 3 degree/second, 2000 foot per minute climbing turn to the right. You will hold the turn for one minute in which time you are to change heading 180 degrees and altitude 2000 feet. At the end of one minute, 180 degrees of heading change and an increase in altitude of 2000 ft. you are to continue the standard rate 3 degree per second turn and maintain your new altitude of 26,000 ft. When the second minute has elapsed you should be on your original heading of 0 degrees and Mach 1.1. Your altimeter should read 26,000 feet. Maintain this vector for another 30 seconds. If you are not on your desired speed altitude and heading return to them during the 30 seconds of SLF.

Remember, after completing the climbing turn to the right maintain that altitude and continue the standard rate turn. Do not continue to climb after completing the first minute of the 360 degree standard rate turn. Maintain your altitude of 26,000 ft. and complete the turn.

You will have a diagram of the maneuver on your knee pad for a reference while performing the maneuver. Remember to keep track of your time as well as the altitude and heading programs.

Do you have any questions?

APPENDIX D

Pilots' Evaluative Comments

Although evaluations of both the Simulator and the Audio-Visual Trainer were requested, the pilots said very little about the former and a great deal about the latter. As a matter of fact, only four pilots commented about the simulator. Two pilots mentioned the differences in "control feel" and "response quickness" of the UDOFTT as compared with light planes which they were accustomed to flying, and the other two made some minor complaints concerning the trim system of the simulator. Apparently, the rating scale prepared for evaluating the simulator covered most of the topics of interest, leaving little additional to be mentioned in the oral de-briefings.

On the other hand, all of the pilots evaluated the Audio-Visual Trainer. Comments made by the pilots were re-typed from Stenocord belts. With the exception of adding a few explanatory notes to assist the reader in understanding when the evaluations relate to the Simulator (UDOFTT) or when they relate to the Audio-Visual Device (A-V), the comments are unedited.

Pilot One - "I believe the audio-visual trainer is a definite aid in preparing the subject for the simulator (UDOFTT). The control for the pitch and roll is a bit ineffective in that it takes awhile for the subject to get used to hitting the contacts (A-V). For example, if I believe a stick forward motion is needed to correct for the malfunction, I may push the stick but not hit the forward contact and thus the answer is wrong even though the response is right. I had not flown for several months before entering into this program so that the audio-visual trainer was good for practice before going into the simulator. I did not believe the maneuvers (in the A-V) were too difficult for my flying background and experience. I think perhaps the main reason for my many mistakes were just the fact that I was not current for so many months and was out of practice. To sum up I would say that the audio-visual trainer is a success, both the audio part of it which was clear and distinct and easy to understand and the instructions are easy to follow and the visual part which gave a clear impression of the aircraft panel, and there is no doubt in the subject's mind as to what had to be done."

Pilot Two - "Recalling through the last session on the visual trainer, the only comment that I have was that if we had about two more seconds, I think that probably there would have been much greater response, that is, correct response, to most of the questions. I find that with the continued use of the simulator (A-V) and the greater familiarity with the control responses, the simulator (A-V), is really a very satisfactory trainer in practically all respects."

Pilot Three - "I have only three constructive comments. On several of the (A-V) slides one being a 5 degree bank to the left, heading was off 5 degrees to the right. It appeared to me that my established bank would be sufficient to bring the aircraft back to the course desired, which was the wrong answer, and the right answer was more bank required to the left. The second one was on the order of this only concerning

rate of descent. It was slightly over 2,000 ft. per minute. Everything else was O.K. except we were 200 ft. above our desired altitude. I felt that no correction was needed; however, the correct answer was that we needed more forward stick. And the third thing, mainly, it is a little unrealistic in that you are suddenly confronted with an attitude or reading of the instruments and, of course, something is wrong, it is not exactly what you desire. However, you didn't make it or at least you were not flying actually and making this wrong attitude; and suddenly you have to analyze it and correct it and it seems a little bit too short of time to be able to do that."

Pilot Four - "There would be two comments that I feel would be pertinent; 1) is that the pitch cues (A-V) were very subtle, more so, than what I am used to in light aircraft and I also felt that the (A-V) response time was just a little short. I would say perhaps, another 5 seconds, is in most cases all I would need for the correct response."

Pilot Five - "I have but two suggestions for the visual trainer, the stick in my opinion should have a greater throw, possibly two inches in each movement from neutral - and the second suggestion would be that the instrument panel should be visual at all times between slides; this would help create a scan or help keep a scan coordinated between slides. This could be done in one or two ways in my opinion. No. 1, the circles for each instrument could be painted on the back of the screen or a better method would be to keep the shutter open or at a desired cockpit presentation between slides."

Pilot Six - "Relevant to frame number 23, slide 108: with the right bank already established, the aircraft is only 10° left of heading; an additional right turn in my opinion would overshoot the desired 045. Considering the time element a left correction of bank attitude at that point would roll aircraft out very close to the desired heading. A 5° heading change under actual instrument conditions would be more likely a rudder pressure only. Relevant to slide #211, frame 29, I believe that a student would feel that a reaction is required directly pertinent to the instrument indication present rather than anticipatory reaction of aircraft after control movement was made. Prior slides did not seem to require the same type of anticipatory reaction. The time required for scanning and responding seem to be a little too fast at least for me."

Pilot Seven - "As far as the simulator (A-V) is concerned I found the stick a little bit too stiff and the indentations too close together. I got a few wrong answers because when I was moving the stick the thing caught on the wrong section. I also thought that the time allowed to scan from my experience at least a little bit too short - it should be slowed down just a little. In other words we should be allowed more time to scan the problem given. Another thing in that the problems given was - are so close to being right that in my experience in non-jet aircraft I wouldn't make any changes. Now, except for the above I think this machine is probably one of the greatest training aids that I have come across in my experience of flying and I feel that if I had the use of the machine like this, maybe I would be doing a more competent job in instrument flying."

Pilot Eight -"The only comment that I have is on program #3, the (A-V) programming on #3, or the time sequence is much more comfortable for me than on program 1 and program 2, and the stick was reacting better. There were only a couple of times that I got the wrong reaction with the right impulse. It is a very good idea - a machine like this."

Pilot Nine -"The machine (A-V) is a fine means of portraying aircraft condition and testing against condition response, however, it does not give you a continual condition that you are correcting for. It puts you in a series of events that are there immediately; not ones in which you put yourself in this condition. The condition is put upon you on a time table, and it does not require the individual to think of what may have gotten him there and correct past mistakes or for him to be able to make continuous corrections which may alleviate this problem. The last two sessions in which I was involved, a lot of emphasis was once again put upon a clock; once again this does not give you a continuous sort of events, but rather gives you isolated conditions which you have to delve into separately, not seeing a correction that you make, not being able to make (like I said earlier) a continuous correction which may alleviate any problems that might come up afterward. The second hand on the clock is very very hard to visualize when you are scanning rapidly. The immediate lesson, or the first lesson that we took, on the simulator (A-V)with the audio-visual trainer was one in which they took you from the beginning and give you a complete background of how the instruments work, allowing you to cross-check on the various instruments as you progress in the lesson. The second lesson, however, other than giving you a preview of the past, puts you in a problem which required that you have had past knowledge of the instrumentation as a set-up and have had experience with that instrumentation; some slides contain great detail as to a minute error that might occur in one particular instrument. The facsimiles would be that of a rate of climb or the artificial horizon in conjunction with the rate of climb or the altitude with conjunction to the rate of climb indicator. In one instance they may be off just a half a ball width in the artificial horizon or half of a line and no significance is placed on this unless it is 2,000 ft. per minute rate of descent. However, another case it may be off just a hair and the response that you make is not correct because you did not pay attention to that minute error that existed in the particular instrument."

Pilot Ten -"The first one is controls (A-V) and I thought that I had hit the proper control five or six times and I thought that the right aft and the left forward possibly were wrong when I did it. Second, I thought that you should be told that in a 60° degree bank where the amount of the turn was slow, you wanted an increase in bank. The second one would be: more explicit directions (A-V) on what I should do, if for instance, you have the 60° bank and your turn rate was slow I didn't know whether to keep the 60° bank and leave the turn

as is or whether I should increase over 60° bank, which was against what I thought you should have done. And the third one I felt that there was more than one way to correct any given situation (A-V). For instance, in a highly banked turn reducing the bank with the ailerons would help more in reducing, loss of altitude than using the rudder."

Pilot Eleven - "Feels good - there should be more time (A-V) allowed for reaction because under actual conditions the instruments are under constant observation. This way you would have more time to scan the panel each time and make a correction if necessary. I found it difficult to make the diagonal responses."

Pilot Twelve - "I find that the whole program (A-V) itself was terrific that the timing was right and the plane(UDOFTT) was fast that you had to be fast. If you didn't make the correction within the 5 seconds or what ever you have, you've had it."

Pilot Thirteen - "Time (A-V) for a piston pilot could be a bit longer to allow for proper scanning and figuring of the turns. A stick (A-V) could be more like an aircraft to allow for a normal response, normal or natural response. I believe this device is excellent for scanning practice but requires considerable thinking in a short period of time. In an aircraft you are already aware of the greater percentage of the problem that exist due to the events that have transpired immediately previous to the "that there problem."

Pilot Fourteen - "A visual trainer being static and that it presents slides is unrealistic. A pilot who is accustomed to continuing instrument movements is at a disadvantage in analyzing the situation that has developed as the slides are flashed on the screen. The tendency therefore is to apply some corrective action in the few seconds allotted proper corrective action."

Pilot Fifteen - "The machine (A-V) itself is a fantastic training device, especially for an instrument pilot, who in the course of flying actual instrument has a tendency to become sloppy whereas you cannot become sloppy with the trainer (A-V). The only criticism that I might have of it is that the stick handle should have more throw to allow for the seating position of the pilot. I think if a stationary type seating arrangement were used which would seat the pilot directly in front of the machine and not allow him to move left or right, coupled with more throw on the stick would allow for less error between the pilot and the training device. Sometimes looking at the instrument presentation - or looking over to the left side of the panel I find myself slumping to the left which in turn changes my perspective in relation to the display and in putting in aft stick I find myself adding aft left involuntarily."

Pilot Sixteen - "Difficult to getting stick into diagonal position. Time to react seems a bit short. Not used to type of heading instrument and not used to horizon type used. Aft or forward on horizon is difficult to determine." (All comments concern A-V device)

Pilot Seventeen -"I found this AV to be much more satisfactory than the last time. In addition I found it easier to fly the simulator (UDOFTT)."

Pilot Eighteen -"During the last period of the visual trainer I believe that the visual trainer is very good for improving the cross check of any pilot in training. The stick controls are slightly different than the ones you'll find in the airplane but otherwise suffice the purpose fairly good. I have found that when making a right bank movement and pushing the stick (A-V) to the right that I have been pushing it slightly ahead and to the right which has been giving a bad score."

GLOSSARY

AERODYNAMIC COEFFICIENT — Describes the shape and relative orientation of a body moving through a fluid, i.e., air.

CLOSED-LOOP RESPONSE — The response of a feedback control system with the loop unbroken so that there is no interruption of the closed cycle operation.

C_{m_q} — Change in pitching moment coefficient with varying pitch velocity (pitch damping derivative - non dimensional).

CONTROL STRATEGY — A pattern of control movements including direction and rate fashioned to maintain a vehicle within desired limits.

f_{DR} — Dutch roll undamped natural frequency.

FLEXIBLE COEFFICIENTS — The aerodynamic coefficients which contain the effects of aerodynamic loads upon the elastic structure of the aircraft. Flexible (or aeroelastic)coefficients vary with both Mach and altitude.

FREE AIRFRAME EQUATIONS — The set of equations which describe the dynamic response of an airframe to motions of the control surfaces and/or power settings, and/or external disturbances. These equations will contain the aircraft subsystems (e.g., instruments, engine, hydraulic power boost systems, etc.) as components of gross weights, moments and products of inertia, and center-of-gravity locations but do not consider the dynamic responses of these subsystems.

L_β — Change in rolling moment with variation in sideslip angle (effective dihedral derivative).

L_{δ_A} — Change in rolling moment with change in aileron deflection (aileron effectiveness).

L_p — Change in rolling moment with change in rolling velocity (roll damping derivative).

GLOSSARY (CONT'D)

L_r	Change in rolling moment with change in yawing velocity.
LEAST SQUARES APPROXIMATION TO THE FLEXIBLE COEFFICIENTS	The least squares straight line approximation to the family of curves representing the Mach and altitude variation of a particular stability derivative. The least squares approximation varies linearly with Mach number only.
M_α	The change in pitching moment with varying angle of attack (longitudinal static stability derivative).
$M_{\delta is}$	Change in pitching moment with changes in elevator deflection (elevator effectivenss).
M_q	Change in pitching moment with varying pitch velocity. (Dimensional)
N_β	Change in yawing moment with variation in sideslip angle (static directional derivative).
N_r	Change in yawing moment with change in yawing velocity (yaw damping derivative).
OPEN LOOP RESPONSE	The response to an input of a feedback control system with the loop "broken" at some convenient point so that there is no closed cycle operation or only partial feedback in the system.
$\left\lvert \phi/\beta \right\rvert$	The ratio of the envelope of the bank angle to the envelope of the side slip angle during the Dutch roll. This is relative to yawing contained in the Dutch roll motion.
RIGID COEFFICIENTS	The aerodynamic coefficients representing an assumed inelastic aircraft structure; these coefficients vary only with Mach number.

GLOSSARY (CONT'D)

SHORT PERIOD (SP)	A longitudinal oscillation of an aircraft characterized by changes in pitch angle and angle of attack while essentially at constant airspeed and altitude. So named because of its short period (one second) relative to the phygoid motion.
STABILITY DERIVATIVE	1) Dimensional - describes the change in the force or moment due to a change in the orientation or shape of a body moving through a fluid, e.g., air.
STABILITY DERIVATIVE	2) Non-dimensional - describes the change in the aerodynamic coefficient due to a change in the orientation or shape of a body moving through a fluid, e.g., air.
τ_p	Roll rate time constant.
TRIM FLIGHT	Trim flight is defined as unaccelerated flight, that is, flight along a straight flight path during which the linear velocity vector measured relative to fixed space is invariant and the angular velocity is zero.
τ_s	Spiral mode time constant
Y_v	Change in side force with changing sideslip angle (side force damping derivative).
Z_w	Change in vertical aerodynamic force due to a change in vertical velocity.

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13. ABSTRACT

This is the fourth report in a study program dealing with pilot performance, transfer of training and degree of simulation. The purpose of this study was to repeat a previously conducted transfer of training study using non-jet experienced pilots as subjects. Its primary objective was to determine the training feasibility of using degraded levels of simulation fidelity in an Operational Flight Trainer (OFT). Simulation fidelity was varied by incorporating coefficient changes into the aerodynamic equations of flight such that rigid coefficients and least squares approximations to flexible coefficients served as the experimental conditions and flexible coefficients served as the control condition. On the basis of study results, it was concluded that the feasibility of rigid coefficients for OFT training had been demonstrated; however, the training utility of the least squares approximations was doubtful. It is recommended that further study should be undertaken using other flight regimes and training maneuvers.

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